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THESIS

Weichselian lithostratigraphy, depositional processes and deglaciation pattern in the southern Vättern basin, south Sweden.

Waldemarson, Dan

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Lund University, Department of Quaternary Geology

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by

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A contribution to IGCP project 24
(Quaternary Glaciations in the Northern Hemisphere)

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Title and subtitle Weichselian lithostratigraphy, depositional processes and deglaciation pattern in the southern Vättern basin, south Sweden.					
Abstract In the southern Vättern basin six lithostratigraphic units are distinguished: the Kaptensbo beds, the Rosenlund diamicton, the Sanna beds, the Öxnehaga diamicton, the Ekhaben clay and the Ryhov sand. The Kaptensbo beds were deposited in a glaciolacustrine environment. The unit shows intraformational deformations and was glaciotectonically displaced. The Rosenlund diamicton was deposited by undermelting of a floating glacier. The glacier occasionally grounded and deformed, displaced and/or deposited sediments. The Sanna beds were deposited in a glaciolacustrine environment. The unit consists of sediments deposited in high energy water, glaciofluvial sand and gravel, and sediments deposited in low energy water, glaciolacustrine silt and clay. The unit was glaciotectonically displaced. The glaciofluvial sediments in the unit show paleocurrents towards a southern sector. The Öxnehaga diamicton was deposited in a subaquatic environment. The unit was deposited by debris flows, close to the glacier margin alternatively under a floating glacier. The glacier occasionally grounded and deformed, displaced and/or deposited sediments. The Ekhaben clay was deposited in a glacial lake. The Ryhov sand consists of glaciofluvial sand deposited in a lake with a water level of about 100 m a.s.l. The Ryhov sand shows paleocurrents towards a northern sector. The stratigraphy is used for correlations to surrounding areas. In the investigation area there are indications of two glacier readvances, preceded and followed by glacial lake stages. The glacial lakes have thresholds towards the south or towards the west, at about 220 m a.s.l.					
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Signature Dan WaldemarsonDate 1986-04-25

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Foreword

The deglaciation of southern Sweden is a classical field of research. Several deglaciation models have been presented, often with contradictory and controversial results. These older models are mainly based upon the regional morphology, topography and geological maps combined with often questionable chronological data but not on the lithostratigraphy. The different views have been reviewed by Berglund (1976, 1979). At the Department of Quaternary Geology at the Lund University a project was organized with one group treating the biostratigraphy and deglaciation chronology and an other group the lithostratigraphy and deglaciation pattern and dynamics (Berglund 1976). The project is included in the Swedish program of IGBP-project 24 "Quaternary Glaciations in the Northern Hemisphere" (QG)

The lithostratigraphical subproject was organized by Gert Knutsson and Erik Lagerlund. Nine graduate students were assigned a field study area for which the process of deglaciation was to be determined. These are shown in the map. Lagerlund has been the main supervisor for the graduate students and from 1980 alone the leader of the subproject. Within the group several methodological seminars and excursions were organized and different experts have visited the field study areas (e.g. G.S. Boulton, A. Dreimanis, J. Shaw, C.-E. Johansson). Excursions with other Swedish QG-groups as well as the QG-symposium in Stockholm 1981 have also been of great importance for the progress of our work. As a Swedish QG-subproject our group has received economic support from the Swedish Natural Science Research Council.

The author of the present thesis, Dan Waldemarsson, was studying the Jönköping area in the southern Vättern basin (number 9 on the map). Results from the other field study areas are published or will be published in the near future in the LUNDQUA Thesis series. A preliminary synthesis of our subproject is published in the LUNDQUA Report series, vol. 24 (Lagerlund et al. 1983). In that report a new model of the deglaciation pattern in



The field study areas: 1) the Kristianstad area, Max Åmark (LUNDQUA Thesis 15), 2) the Hässleholm area, Mats Hebrand, 3) the Ängelholm area, Per Sandgren (LUNDQUA Thesis 14), 4) the Laholm area, Joanne Mae Robison (LUNDQUA Thesis 13), 5) the Bolmen area, Bengt Karlgren, 6) the Åsnen area, Per Möller, 7) the Våxjö area, Lars-Olof Jönsson, 8) the Åseda area, Thomas Terne, 9) the Jönköping area, author.

southern Sweden, based exclusively on lithostratigraphical and glacial geological evidence, is presented.

Lund, April 1986

Erik Lagerlund

1 Introduction

The investigation area, the southern part of the Vättern basin (Fig. 1), is a classical area in Quaternary research. The Vättern basin is also a key area in the investigation of the drainage of the Baltic ice-lake and the glacial oscillations of the middle Swedish endmoraine zone.

The present work is made at the Department of Quaternary Geology at the University of Lund, under supervision of docent Erik Lagerlund. The study is part of the IGCP project 24 (Quaternary Glaciations in the Northern Hemisphere, subproject "Deglaciation of the south Swedish highlands").

This investigation was initiated during an excursion with professor Gert Knutsson and docent Erik Lagerlund. Reconnaissance work was made in the investigation area in the summer of 1976. The field work started in 1978 and ended in 1982, later some complementary work was made.

The main purpose of this work is to establish a lithostratigraphy for the south Vättern basin and to study the paleoenvironment during the deposition of the different stratigraphic units. The deglaciation history was also studied.

In the stratigraphic correlation work the main tools have been rock fragment composition, grain size composition, paleocurrent analysis and the relative stratigraphic position of the different units. A big part of this investigation deals with sedimentary aspects of diamictons deposited in a subaquatic environment.

The conclusion of this work gives information about glacier oscillations and glacial lakes in the Vättern basin.

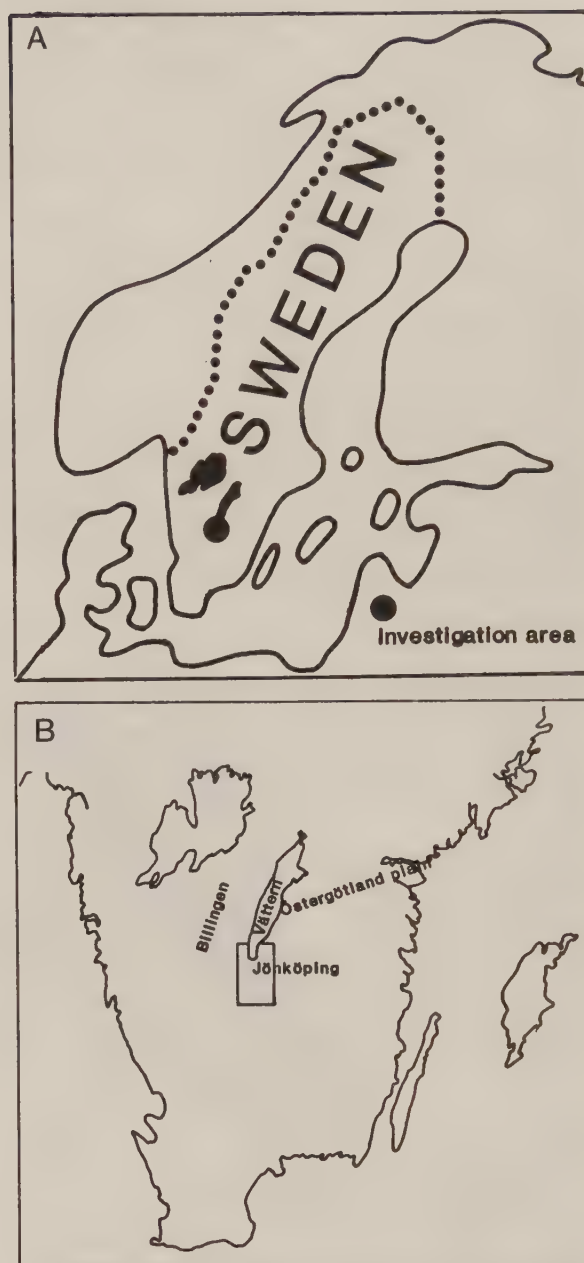


Fig. 1. Location of the investigation area
a) Feno-Scandia b) Southern Sweden.

2 Investigation area

The investigation area is situated in central southern Sweden (Fig. 1) and is restricted to the close vicinity of the south Vättern basin and its southern extension (Fig. 2). Most parts of the investigation area is situated in the county of Småland. The town of Jönköping is situated in the central part of the investigation area.

There are many lakes of different origins in the area. The biggest is Lake Vättern and other important lakes are Lake Landsjön, Lake Stensjön, Lake Tenhultasjön, Lake Lovsjön, Lake Eckern, Lake Färgen and Lake Sandsjön (Fig. 2).

The main part of the studied area drains to Lake Vättern, which drains in its north-eastern end towards the Baltic (Fig. 3). The southern part of the investigation area drains southwards by the river Lagan, which enters the Kattegatt at Laholm.

Huskvarnaån, Tabergsån, Lillån and Domneån are minor streams entering the Lake Vättern. These streams have built out deltas at the entrance of Lake Vättern (Fig. 2).



Fig. 2. Topographic map of the investigation area, with 50 m equidistance.

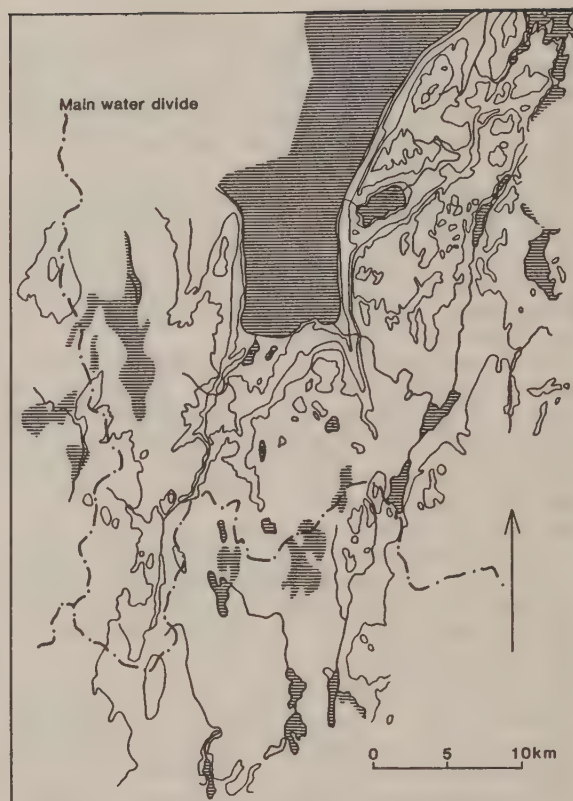


Fig. 3. The main water divide in the investigated area.

2:1 The bedrock

The investigated area is dominated by crystalline rocks, but in the Vättern basin and in the Landsjödalen valley younger sedimentary rocks are found.

2:1:1 Crystalline rocks

The basement in the investigated area consists mainly of granites, which belong to the so-called Småland granites, which are associated to the Småland volcanic rocks. These rocks were formed between 1700-1750 million years ago (Persson in Svantesson 1985).

The basement consists of granite, hornblende granite, gneiss granite, gabbro, diorite and syenite (Fig. 4).

In the southern part of the area separate massives of hyperites are found (Fig. 4). The hyperite was formed about 1300 million years ago (Magnusson et al 1963).

2:1:2 Sedimentary rocks

Sedimentary rocks from the Visingsö Group were found in the Vättern basin and in the Landsjödalen valley (Fig. 4).

The Visingsö Group consists of sandstone, siltstone, shales, conglomerates and limestones (Collini in Geijer et al 1951, Vidal 1976). The Visingsö Group was formed between



Fig. 4. Bedrock map. The map is a compilation of the bedrock maps in the description to the geological maps SGU ser Aa 123, 193 and SGU ser Ae 59.

700 and 850 million years ago (Vidal 1976).

2:1:3 Structures in the bedrock

In the investigated area there are many examples of tectonic movements. About 1300 million years ago the protogin zone (Magnusson et al 1963) was formed during extensive tectonic movements. The Vättern basin (Figs. 4 and 5) is a graben, formed during a late phase of the Precambrian (Axberg and Wadstein 1980).

2:2 Topography

In the following text, + altitude means above sea level and - altitude means below sea level.

The topography in the investigation area is mainly dependent of the topography of the basement (Chapter 2:1). The Vättern basin is the dominating feature. Lake Vättern is today artificially regulated to about 88.5 m at Motala in the north eastern end of the lake. The greatest depth of Lake Vättern is about 119 m (Norrman 1964), which is about -30 m. Axberg and Wadstein (1980) have seismically found that there is a maximum of about 375 m

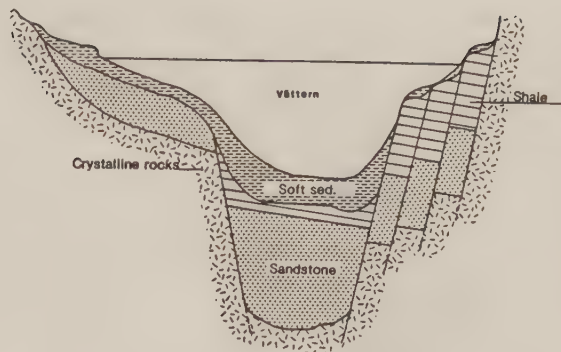


Fig. 5. Section through the Vättern basin according to Axberg and Wadstein 1980.

of unconsolidated sediments under the bottom of the southern parts of Lake Vättern on top of the Visingsö Group of Rocks. In the early forties a well-drilling was made in Jönköping town to the sandstone of the Visingsö Group. Found here are approximately 195.5 m of unconsolidated sediments (Ullerstam 1940). Logs from this drilling have not been obtained, and the age of the unconsolidated sediments is unknown. Close to the shores in the southern parts of Lake Vättern there are heights of over +300 m (Fig. 2). This gives a relief of the area of 300 m, within about 7 km, to the bottom of the lake and of more than 600 m to the top of the Visingsö Group of Rocks. This is an alpine relief.

The southward continuation of the Vättern basin is divided by the Bondberget hill into the Tenhult valley and the Taberg valley. The Tenhult valley continues for several tenths of kilometers southwards, while the Taberg valley ends south of mount Taberg. These valleys are of tectonic origin (Chapter 2:1).

The topography outside the Vättern basin can be divided into three topographical regions. These regions are closely related to the basement regions (Chapter 2:1).

East of the Vättern basin the crystalline rocks are divided into big blocks separated by deep valleys, such as the Landsjödalen valley. Each of the big basement blocks is divided into minor blocks separated by deep and narrow valleys. In the major valleys the depths of the unconsolidated sediments is considerable (more than 50 m in Landsjödalen valley), while in the elevated areas and in the narrow valleys there is only a thin cover of unconsolidated sediments.

In the protogin zone (Chapter 2:1), the continuation southwards of the Vättern basin, the depth of the unconsolidated sediments is considerable. In this area the topography is mainly a product of the morphology of the unconsolidated deposits. North of the threshold area (Fig. 3) the morphology consists of ravines and other erosional features. South of the threshold there is a narrow zone of sand and gravel in positive landforms like mounds, plateaux and ridges. Further southwards this zone grades into an almost flat sandplane with kettle holes. The frequency of kettle holes diminishes southwards (Waldemarson 1981, 1983).

West of the Vättern basin there is a large basement plateau, in which there is a rather deep cover of unconsolidated sediments, both

diamicton and sorted sediments. Uncovered bedrock is rare. On the slopes to the Vättern basin there are large sandfields with erosional morphology (Waldemarson 1983).

3 Earlier works in the investigation area

The Vättern basin is a classical area in Swedish Quaternary research. New scientific papers about the geology in the Jönköping area have been presented every decade since 1890.

Except for the chronology of the deglaciation there are two tasks that have occupied geologists working in the area. One is the existence of elevated ice-dammed lake levels, the other is an oscillation of the glacier front in the Vättern basin.

3:1 Glacial lakes in the Vättern basin

De Geer (1893) is the first to express the possibility of elevated glacial lakes in the Vättern basin. Hollender (1899) is the first one who studies elevated glacial lakes in the Vättern basin. He assumed that the sand and gravel fields, at levels above +200 m, south of Jönköping were deposited in ice-dammed lakes. From the extension of the sand fields he proposes the extension of the glacial lakes. Hollender also mentions that an "endmoraine like" ridge is situated at Tahe near Taberg (Fig. 2). These two observations would be of importance for the further Quaternary research in the Jönköping area. Hollender's ideas clearly influenced Munthe and Sandegren (1907) in the description of the geological map of Jönköping. Munthe and Sandegren (1907) use the glacial lake model in the work with the map and show the extension of a "Vättern glacial lake". Because of a relict fauna in the Vättern basin they believe that all sediments below +110 m were deposited or reworked in a marine environment.

Three years later Munthe (1910) presented more details of the glacial lakes in the Vättern basin. He thought that the sand terraces on the northern side of Taberg at about +245 m were the highest shore lines from the ice-dammed lakes in the Vättern basin. The terraces at +300 m at Forserum were deposited in local glacial lakes.

Nilsson (1939) enlarges the proposed glacial lakes in South Sweden (Fig. 6). He can trace elevated shore-lines from the Bolmen basin, about 100 km south of Jönköping into the Vättern basin. Nilsson calls this huge glacial lake "Storbolmen". Storbolmen was drained westwards and a first "Vättern glacial lake" was formed. After an oscillation of the glacier front a "second glacial lake" in the Vättern basin was formed. The second glacial lake had, in the beginning, a drainage south- and westwards to the thresholds at Tenhult, Barnarp, Taberg and Olsbo (Fig. 2). Later on, the second glacier lake was drained eastwards to the Baltic Ice Lake through thresholds at Ingeryd, Grankärr and the Stavadalen valley. After the drainage eastwards the second glacier lake was drained westwards at the Flatan valley. After the drainage at Flatan Nilsson (1939) thinks that the second glacier was connected to a glacier lake in the Tidan basin and a "Tida-Vättern glacial lake" was formed. This lake was drained southward through the Åtran valley (Nilsson 1953). When the retreating ice-front reached the Östergötland plain the Tida-Vättern glacial lake was drained eastwards

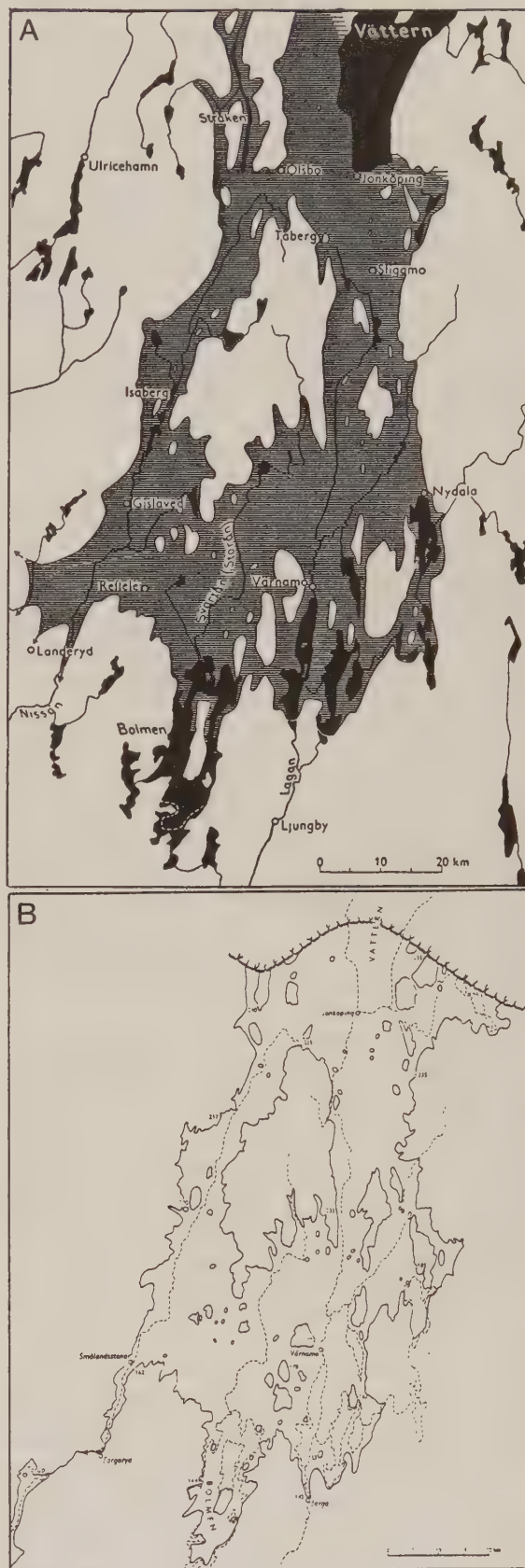


Fig. 6. The extension of elevated glacial lakes according to a) Nilsson 1939, b) Nilsson 1953.

to the Baltic Ice Lake.

Munthe (1910) shows a more detailed picture of the glacial lakes in the Vättern basin, but the principal ideas from his earlier works were not altered.

In 1942 G. Lundqvist raises doubts about the high elevated glacial lakes in Småland. He discovers that sand is found under almost every peatbog and not clay, which should have been expected if large ice-dammed lakes had existed in the area. Lundqvist does not think that the sand fields between Jönköping and Värnamo were deposited in glacial lakes.

Nilsson (1953) ignores Lundqvist's (1942) doubts concerning elevated glacial lakes and presents diagrams of elevated shore-lines from "Storbolmen and the Vättern glacial lake complex". In this work the highest shore-line is at +261 m at Taberg. This is 21 m higher than his earlier suggestion. This huge glacial lake was drained in a complicated way intermittently eastwards and westwards. The picture becomes even more complicated by an oscillation in the Vättern basin.

Munthe (1910, 1940) suggests three different thresholds westwards of the Baltic Ice Lake, and thus also for the Vättern glacial lake, at the northern tip of Mt. Billingen, while Nilsson (1939, 1953) has recorded only one drainage of the Baltic Ice Lake.

On morphological and sedimentological grounds Norrman (1963) questions the drainage of the Vättern glacial lake at Flatan and the formation of the Tida-Vättern glacial lake. Later Norrman (1971) shows that some of Nilssons (1953) shore-lines are erosional marks from subglacial drainage.

Nilsson (1968) admits that the highest shore-lines from Taberg and other places were not formed in big open glacial lakes but in small local ice-dammed lakes. One of the major reasons for Nilsson's retreat in the glacial lake question is the subglacially formed eroded meltwater channels found by Hoppe (1952). Nilsson (1968) means that the highest shore lines in "Storbolmen" are +240 at Taberg, which is 21 m lower than he earlier thought and identical with his first suggestion in 1939.

In 1968 Nilsson also presents a varve chronology between Skåne and Stockholm. His key sections in this work are two sites in the northern end of Lake Bolmen. The sites are called Åby and Fridhäll. Here he finds more than 1000 varves below approximately 4 m of sand. Nilsson does not comment the origin of the superimposing sand. The varves from Åby and Fridhäll are correlated with a varve diagram from the Malexander delta in Östergötland, which is situated in another basin as Bjelm (1976) points out, while the varve diagrams from Bogla south of Jönköping are not possible to correlate to the varve diagrams from the Bolmen area.

In 1965 van der Tak-Schneider describes fossil ice-wedges from areas below glacier lake level described by Nilsson (1939, 1953, 1968) and by Munthe (1910, 1940). The lowest ice-wedges must have been formed after the drainage of the Vättern basin, at the northern tip of mt. Billingen.

Norrman (1971) shows, both sedimentologically and morphologically, that the Skallhult plateau, which both Munthe (1910, 1940) and Nilsson (1953, 1968) interpreted as a marginal delta, is a subaerial formation deposited with ice-contact slopes on all sides of the plateau. Norrman (1971) finds no higher

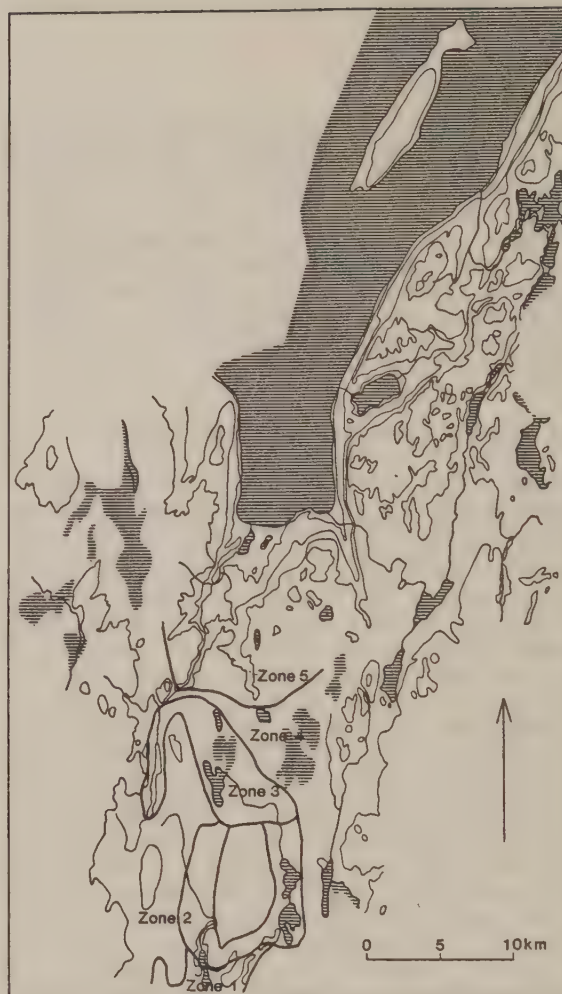


Fig. 7. Morphological regions of glaciofluvial sediments according to Waldemarson (1981).

shore-lines at Hjo than +150 m, which, due to the isostasy, corresponds to +110m at Jönköping (Norrman 1964, 1979).

Bjelm (1976) shows that Nilsson's (1968) varve chronology between Bolmen and the Malexander delta in Östergötland is sedimentologically unsound, because there was no hydrological communication (Nilssons 1968 own statement) between the Bolmen and the Åsunden basin. Bjelm (1976) also shows that the drainage valley at Brånstorp, northwest of Eksjö, pointed out by Nilsson (1953), has very few traces of fluvial erosion.

Bjelm (1976) also shows that the glacier was active during the deglaciation with a zone of stagnant ice in front of the glacier margin. Norrman (1978) shows that the proposed glacial lake deposits (Nilsson 1939, 1953, 1968 and Munthe 1910, 1940) are subaerially deposited in large sandurs.

Waldemarson (1978) can not find any erosional traces in the proposed drainage valleys at Grankärr and the Stavadalen valley.

Waldemarson (1981) subdivides the sandy sediments south of Jönköping into 5 different morphological and genetical areas (Fig. 7). The southernmost area lies south of Vaggeryd and consists of a sandur plain with very few kettle-holes. The second area lies between

Vaggeryd and lake Eckern and consists of a sandur plain with many and large kettle-holes. The third area lies south of the main waterdivide (Fig. 3) and consists of mounds, plateau and short ridges of gravely sand. These positive morphological elements have ice-contact morphology and internal structures formed by the release of ice-support. The fourth area is found around the main waterdivide and consists of a flat or an undulating sandur plain. The fifth and northernmost area consists of a large ravine landscape. The ravines are cut in sand and coarse silt. These sediments were deposited in a glacial lake between the waterdivide and the glaciers in the Vättern basin. This huge discharge and sediment supply diluted the low energy water sediments.

3:2 Glacier oscillation in the Vättern basin

Glacier oscillation in the Vättern basin is an often discussed subject. In the description of the geological map of Jönköping Munthe and Sandegren (1907) present evidence of at least one large readvance in the Vättern basin. They refer to tills overlying glaciolacustrine and glaciofluvial sediments and the occurrence of two different sets of striae. Munthe and Sandegren (1907) also describes the extension of this readvance. Sandegren (1917) describe glaciotectonically displaced sediments from a site south of

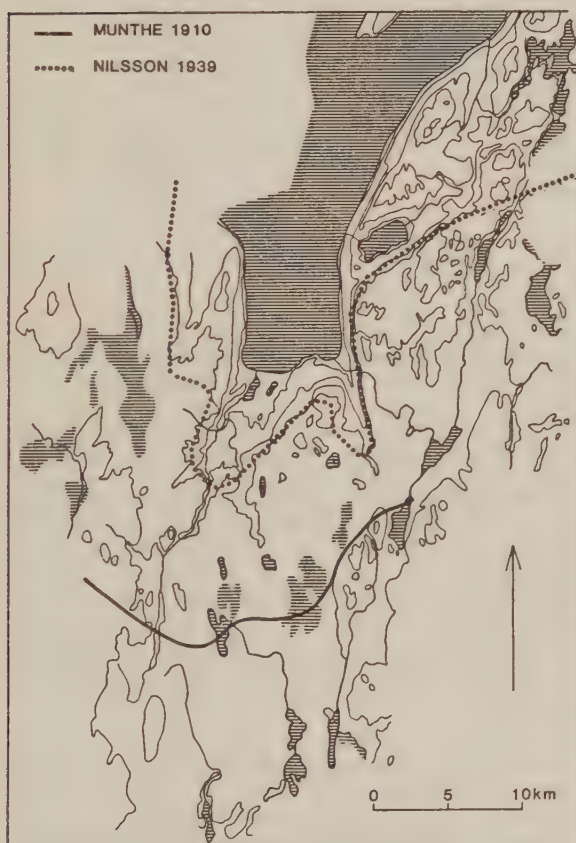


Fig. 8. The extension of glacier oscillations in the Vättern basin according to Munthe 1910 and Nilsson 1939.

Munksjön in Jönköping. He states that the oscillation only lasted about 50 years. Nilsson (1939, 1953, 1968) believes that the glacier oscillations in the Vättern basin has a smaller extent than Munthe believes (1907, 1940) (Fig. 8). Nilsson concluded (1939, 1953, 1968) that the sand and gravel plateau at Rogberga, Barnarp, Axamo and Svedmon (Fig. 2, 122) are marginal deltas, deposited at the maximum extent of the "Taberg readvance". Mörner (1969) uses the same extension of the "Taberg readvance" as Nilsson does (1968). Bjelm (1976) describes a site with three different till units. The site is situated outside the maximum extent of the glacier oscillation in the Vättern basin, according to Nilsson (1939, 1953, 1968), but well inside the oscillation described by Munthe (1907, 1940). Waldemarson (1981) proposes that the glacier oscillation reached south of the main waterdivide at least to the area around lake Eckern (Fig. 2).

3:3 The deglaciation chronology in the Vättern basin

Nilsson (1968) geochronologically dates the first deglaciation to 9 200 BC (11 150 BP) and the maximum of the oscillation to 9100 BC (11 050 BP). Mörner (1969) dates the "Taberg phase" biostratigraphically and with C^{14} to 9 000-8 800 BC (10 950-10 750 BP) and correlates the "Taberg phase" with the "Salpausselkä I phase". Bjelm (1976) thinks the oscillation in the Vättern basin started in the late Bölling Chronozone (Mangerud et al 1974) and lasted through the Older Dryas Chronozone. Berglund's (1976, 1979) review of the marginal deposits in southern Sweden presents a new picture of the deglaciation chronology in southern Sweden, but for the south Vättern basin a question mark still exists. In Lagerlund et al (1983) the first oscillation is correlated with the Trollhättan line, which is dated by Berglund (1976, 1979) to 12 200 BP and a second readvance is correlated with the Levene line, about 200 years later, 12 000 BP. Berglund and Mörner (1984) date the Trollhättan line to 12 200 BP and the Levene line to 12 000 BP. Björck's and Digerfeldt's (1984, 1986) studies on the western side of Mt. Billingen show a first deglaciation of the northern end of Mt. Billingen and a first drainage of the Vättern basin and the Baltic Ice Lake at 11 200-11 300 BP. A readvance is dated 11 000-10 500 BP and a final deglaciation around 10 400 BP.

3:4 Other studies in the Vättern basin

Gillberg (1965) studies the glacial transport out of the Vättern basin. He studies the rock fragment composition in "tills" and finds an almost radial spreading, except in the northern sector, of the Visingsö Group of Rocks. Gillberg (1965) also find unusually high amounts of Visingsö Group of Rocks in the till southeast of known outcrops. He explains this as unknown outcrops of the Visingsö Group of Rocks.

4 Methods and terminology

In the geologic literature there is little agreement about the terminology in field methods. In this chapter the terminology used will be explained and references will be given for depositional processes and terminology.

4:1 Maps and airphotos

The investigation area has been thoroughly studied on topographic maps of different scale. Frequently used, is the topographic map in 1:50 000 with 5 m equidistance, issued by Statens Lantmäteriverk i Gävle, and a 1:20 000 topographic map with 2 m equidistance, obtained from Stadsingenjörskontoret in Jönköping. A topographic map in scale 1:4000 with 2 m equidistance over the city of Jönköping has also been widely used. Used topographic maps in 1:50 000 are: 7D U1-ricedamm SÖ, 7E Jönköping SV, 6D Gislaved NÖ and 6E Nässjö NV.

Most of the studied area is covered by geological maps in a scale 1:50 000. In the southern part of the investigation area only one geological map in a scale 1:200 000 is available. Relevant maps are: SGU ser Aa 123 Jönköping, 131 Gölle, 193 Gränna and SGU ser Ab 14 Nydala. A new quaternary geological map, covering the area of the topographical map 7E Jönköping SV (Svantesson 1985). Reconnaissance maps in scale 1:10 000 have kindly been put at my disposal by Statsgeolog Sven I. Svantesson.

Airphotos of an approximate scale of 1:30 000 of the investigation area have been carefully studied and a geomorphologic map of the area has been presented earlier (Knutsson and Lagerlund 1979). The airphotos were obtained from Statens Lantmäteriverk i Gävle.

To obtain a 3-dimensional picture of the geology in the studied area many drill logs and water-well records were studied at Stadsingenjörskontoret in Jönköping and at the well archives at SGU in Uppsala. At the SGU library old field diaries have been studied.

4:2 Field work

The field work started with a reconnaissance of the investigation area. Next step was detailed sedimentological studies in open pits and sections. In the Jönköping area many of the sections are coastal cliffs but some of them are too wide and high to be totally cleaned and investigated. In these sites logs have been described and contacts of different units have been followed laterally. To get photos of the sections a boat was borrowed. Smaller sites were usually completely cleaned before pictures were taken and the stratigraphy was described. Details especially in the boundaries between units were sketched and close-up photos were taken. Fabric analyses, paleocurrent measurements and measurements of tectonic properties were also made in the sections.

In the investigated sections the following properties were noted: 1) grain size composition, 2) grain shape, 3) grain roundness and a gross rock fragment composition.

Phi (φ)	Size Class	mm	Field
-12		4096	GRAVEL
-10	Boulder	1024	
-8		256	
-6	Cobble	64	
-4	Pebble	16	
-2		4	
-1,75		3,36	
-1,5	Granule	2,83	
-1,25		2,38	
-1,0		2,00	
-0,75		1,68	SAND
-0,5	Very coarse sand	1,41	
-0,25		1,19	
0,0		1,00	
0,25		0,84	
0,5	Coarse sand	0,71	
0,75		0,59	
1,0		0,50	
1,25		0,42	
1,5	Medium sand	0,35	
1,75		0,30	SILT
2,0		0,25	
2,25		0,210	
2,5	Fine sand	0,177	
2,75		0,149	
3,0		0,125	
3,25		0,105	
3,5	Very fine sand	0,088	
3,75		0,074	
4,0		0,0625	
4,25		0,053	CLAY
4,5	Coarse silt	0,044	
4,75		0,037	
5,0		0,031	
6,0	Medium silt	0,0156	
7,0	Fine silt	0,0078	
8,0	Very fine silt	0,0039	
9,0		0,0020	
10,0	Clay	0,00098	
11,0		0,00049	
12,0		0,00024	

Fig. 9. The Udden-Wentworth grain size scale.

1) **grain size composition:** In the field, the Udden-Wentworth grain size scale was used (Fig. 9).

2) **grain shape:** In the descriptions in the field Zingg's (1935) classification of grain-shape was used (Fig.10).

3) **grain roundness:** In the field as well as in the laboratory Powers (1953) silhouette chart was used for the description of grain roundness.

The directional properties are important in paleoenvironmental reconstructions and stratigraphic work. 1) fabric analyses, 2) paleocurrent analyses and 3) measurements of tectonic properties were made in many sections.

1) **fabric analyses:** In the fabric analyses the dip and the direction of the clast long axes were measured. At least 25 readings were measured. The pebble sized clasts were dug out of a 20x20 cm wide and 10 cm thick cube in a shelf in the section. The fabric analyses were statistically treated according to Mark (1973, 1974). The analyses are plotted in an equal area net by a computer program written by C. Corbete at Ohio State

University. Fabric is a standard method and a widely used tool in determining the paleocurrent directions in fluvial and turbidite sediments and the direction of shear in tills and debris flow deposits. Fabric has also been used as an indicator of paleoenvironment and is one of the major tools to distinguish subglacially deposited tills from flow tills (Boulton 1968). Recent studies in modern and old sediments (Lawson 1979, Carter 1975, Lewis et al. 1980, Enos 1977, Hampton 1975, Walker 1975b, own experience from Svalbard) have shown that preferred orientation of clast long axes also are common in sediment gravity flows. Great care should be taken when fabric is used for paleoenvironmental investigations. Fabric analyses were mainly done in diamictic material.

2) paleocurrent analyses: paleocurrent analyses have been used in many sections to determine the drainage pattern of the Vättern basin. Most frequently used was the determination of the maximum dip of the inclined laminae in trough- and planar cross-laminated sands. A gross direction of flow was indicated from the foresets of current ripples.

3) tectonic properties: Most sediments in the Vättern basin are disturbed and/or displaced by mass- and/or glaciotectionic movements. The terminology of tectonic structures is according to Hobbs et al. (1976). The true strike and dip of faults and foldaxes were usually measures in the field but sometimes the directions were constructed using the apparent strike and dip of the laminae in the limbs.

After descriptions and analyses in the sections samples for grain size composition and rock fragment analyses were collected. Geological mapping was made in interesting parts of the investigation area. The geological mapping recovered many new striae and a special striae investigation was done in the area north of Lake Landsjön.

4:3 Laboratory methods

4:3:1 Grain size analyses

About 320 samples were collected and analyzed. Most samples were sieved and samples with more than 10 % fines (less than $\phi 4$) were also analyzed with the hydrometer analysis (Gandal 1952). Some samples with very high contents of fines were analyzed in a Micro Metric Sedigraph. The samples were plotted in cumulative-curves and in a frequency diagram with half- ϕ intervals in an Udden-Wentworth grain-size scale (Fig. 9). Statistical treatment, in order to compare different samples, has been used according to Folk and Ward, 1957. Mean, sorting, skewness and kurtosis were calculated. The verbal texture scale used in the field is shown in Fig. 10. The verbal scale of sorting is according to Folk and Ward, 1957 (Fig. 11).

4:3:2 Rock fragment composition

In collected samples, with more than 150 particles $\phi 1.50$ the rock fragment composition was analyzed. Different rock fragments were separated either under a magnification glass or in a binocular microscope with a magnification of about 10 times. At least 150

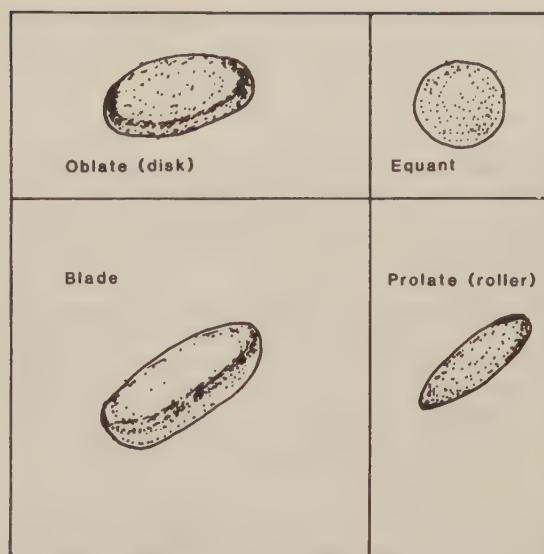


Fig. 10. Grain shape according to Zingg (1935).

grains were counted, but the normal amount is about 300 gravel particles. Four main rock types were separated: 1) crystalline rocks, 2) Paleozoic limestone, 3) shale and 4) sandstone from the Visingsö Group.

The crystalline rocks consist of a big variety of crystalline archaean rocks, sometimes weathered. More than 50 % of the basement in the investigation area consists of igneous rocks (Fig. 4).

The nearest outcrop of paleozoic limestone is in the Östergötland plain, more than 50 km north of Jönköping. The limestone is gray or red and displays shattered fossils. The limestones are always well rounded and usually prolate.

The shale from the Visingsö group occurs in three different varieties. Most common is a black or grayish-black fine-grained variety giving a light gray flour when scratched. The second kind is a yellowish gray or reddish gray siltstone. This variety is usually not as well sorted as the black shale and mica flacs are often found. The third variety is an ochre-coloured very soft siltstone with a high carbonate content. This kind is seldom found in the samples. The sandstone from the Visingsö Group of Rocks is usually fine grained. It is white or gray, but red and green varieties also occur.

The ratio of sandstone and shale in the rock fragment analysis has no significant stratigraphic importance and they are presented together as the Visingsö Group of Rocks. Only the percentages of crystalline

ϕ	0,35	very well-sorted
0.35	—	0,50 Well-sorted
0,50	—	1,00 moderately sorted
1,00	—	2,00 poorly-sorted
	—	2,00 very poorly-sorted

Fig. 11. Verbal scale for sorting according to Folk and Ward 1957.

rocks and Paleozoic rocks are compared with the Visingsö Group of Rocks.

4:4 Sedimentary structures

The terminology and classification of sedimentary structures is used in a way similar to Robison's (1983). The terminology is purely descriptive and the structures are geometrically classified.

The terms, unit, bed and laminae in this work refer to sediment layers distinguishable from over- and underlying units. A sediment layer distinguished in a section is called a unit. There can be many beds in a unit and in a bed one or many laminae. There is no limiting thickness to any of these terms.

Units, beds or laminae can either be horizontal or inclined. Inclined laminae are called foresets. A unit with a particular internal structure is referred to as a set and many sets of the same kind make up a coset (Fig. 13). The type of bedding and lamination distinguished, is perpendicular to the bedding plane and perpendicular and parallel to the paleocurrent direction.

4:4:1 Bedding

Two kinds of bedding (Fig. 12) are distinguished in the investigation area: 1) **trough-bedding** and 2) **planar-bedding**.

1) **Trough-bedding**: the bedding-planes are concave both parallel and perpendicular to the paleocurrent. The underlying bed is usually eroded.

2) **Planar bedding**: the bedding-planes are parallel or subparallel. The beds are continuous in the current direction and much longer than the bed thickness.

4:4:2 Internal structures

The internal structures of the beds can be differentiated into six types (Fig. 13):

1) **horizontally laminated**: The bed is horizontally laminated when the laminae are parallel or subparallel with the lower bedding plane.

2) **cross-laminated** (or foreset laminated): The bed is cross-laminated when the internal

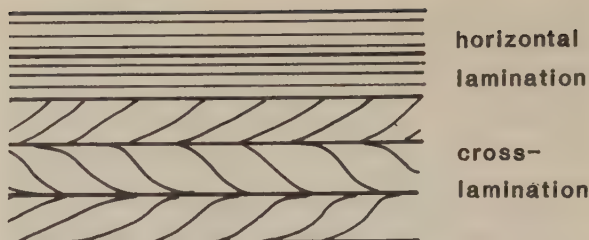


Fig. 13. Types of internal structures.

laminae are inclined towards the lower bedding plane and the thickness of the set exceeds 0.05 m. The contact to the lower bedding plane is either tangential or angular.

3) **small-scale cross-lamination**: Small-scale cross-lamination is used for all kinds of ripples-drift cross-lamination. The laminae are inclined toward the lower bedding surface and the thickness or the individual sets do not exceed 0.05 m.

4) **graded**. A lamina is graded when the grain-size varies in a vertical section. Normal grading is when the texture gets successively more fine-grained upwards and inverse grading is the opposite, the grain-size increases upwards. A special kind of grading, is coarse tail distribution according to Middleton (1967) or longest clast grading according to Walker (1975a). In this type of grading only the coarse tail of the grain-size distribution varies in the vertical section.

Inverse grading is unusual, but exists sometimes in a combination with normal grading. This is called inverse-normal grading. In this type the inverse grading is found in the lower part of the unit and the normal grading appears in the upper part (Walker 1975, Fisher and Mattinson 1968, Fisher 1971).

5) **Massive**. A lamina is massive when there are no visible internal structures.

6) **Draped laminated**. A bed is draped laminated when it reflects the morphology only of an underlying unit or bed (Shaw 1975).

4:4:3 Small-scale cross-lamination

The small-scale cross-lamination is divided into three kinds of ripple-drift cross-lamination. The classification is a modification of Jopling and Walker (1968) and according to Robison (1983 Fig. 14).

1) **type A ripples**. Type A ripples is a small-scale cross-lamination composed entirely of climbing sets with sediment preservation only on the lee side of the flow separation point (Jopling and Walker 1968).

2) **type B ripples**. Type B ripples is a small-scale cross-lamination composed of climbing sets with at least some preservation on the stoss-side and a much higher preservation on the lee side of the flow separation point.

3) **sinusoidal ripples**. Sinusoidal ripples is a small-scale cross-lamination with about equal aggradation on the stoss side and on the lee side of the flow separation point. Usually there is a small lateral displacement rather than perfect vertical superimposition. The three ripples types usually grade into each other and the sinusoidal ripples often

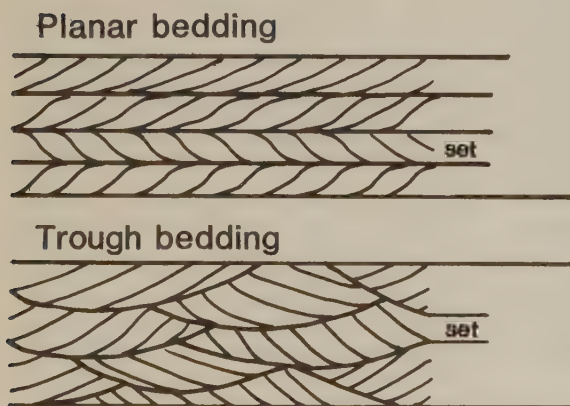


Fig. 12. Used types of bedding planes.

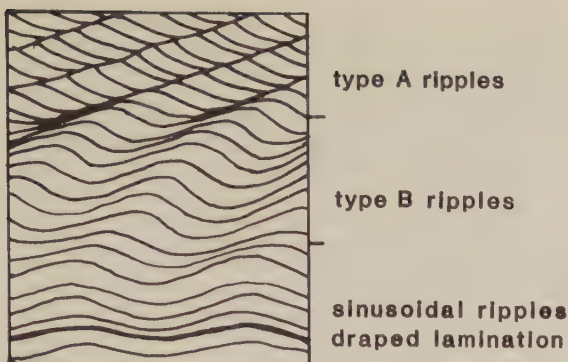


Fig. 14. Types of ripples according to Jopling and Walker (1968).

grade into horizontally laminated silt.

4:5 Facies types and facies code

In the geological literature there is a great variety in the terminology of structures, textures and sedimentary processes. In this thesis a modification of the lithostratigraphic terminology of Eyles et al. (1983), modified after Miall (1977) has been used in log descriptions and figures (Fig. 15). It has been complemented with properties like colour, rock fragment composition, fabric etc.

4:5:1 Lithofacies code

In the lithostratigraphic terminology described by Eyles et al. (1983) a letter code is used for different units and their properties. Capital letters are used for main textural properties possible to distinguish in the field. D=diamicton, G=gravel, S=sand and F=fine-grained material (silt and clay). Lower case letters stand for major primary textural or structural properties. In the Jönköping area no clast-supported diamictons were found and the second letter in the code of Eyles et al. (1983) was excluded. Used lithofacies terminology with descriptions is presented in table 1.

4:5:2 Unit contacts

Contacts between different stratigraphic units are usually very interpretative. In the text and in the lithofacies code four types of boundaries have been recognized (Fig. 15). 1) **erosional contact**. Erosional contact is a boundary between units with evidence of erosion (including material being incorporated into the upper unit).

2) **conformable contact**. Conformable contact is a purely depositional boundary with no signs of erosion or deformation of over- or underlying units. Grading contact is one kind of conformable contact where one unit is grading into the other.

3) **loaded contact**. The loaded contact shows evidence of loading for instance convolute bedding or other water-escape structures.

4) **interbedded contact**. An interbedded contact means no sharp boundary. It is a zone where laminae of the upper and lower units

are interfingering.

4:6 Description of tills and sediment gravity flows

Detailed studies of sedimentary structures, facies types and lateral as well as vertical changes of facies give much information of paleoenvironment and sedimentary depositional processes. To avoid general discussions in the descriptive chapters about terminology of tills and sediment gravity flows the terminology used will be explained below.

4:6:1 Diamicton.

Diamicton is a poorly sorted admixture of most fractions. Diamictons can be deposited in 1) subglacial, 2) subaquatic and 3) sub-aerial environment.

1) **subglacial environment**. Diamicton

Facies code

Symbols

Diamicton, D:

Dm: massive diamicton

Ds: stratified diamicton



Gravel, G:

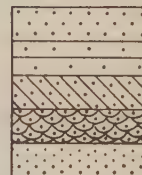
Gm: massive gravel

Gh: horizontally laminated gravel

Gp: planar-bedded cross-laminated gravel

Gt: trough-bedded cross-laminated gravel

Gd: deformed laminated gravel



Sand, S:

Sm: massive sand

Sh: horizontally laminated sand

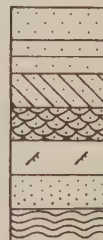
Sp: planar-bedded cross-laminated sand

St: trough-bedded cross-laminated sand

Sr: small-scale cross-laminated sand

Sg: graded sand

Sd: deformed laminated sand



Fine grained, F:

Fm: massive fines

Fl: laminated fines

Fd: deformed laminated fines



wedge

clasts

Intraclasts

water escape structures

erosional contact

conformable contact

loaded contact

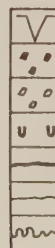


Fig. 15. Lithofacies code and symbols.

deposited directly from a glacier is classified as till. In the subglacier environment three different processes of till deposition can theoretically be distinguished a) lodgement till (Chamberlain 1894, Boulton 1971, 1982, b) basal meltout till (Shaw 1979, Halvorsen and Shaw 1982), c) material dropped from the sole of the glacier and debris slumping or sliding into a subglacier cavity (Boulton 1982).

a) lodgement till is formed when the frictional force of a single particle or an aggregate particles is higher than the yield strength of the glacier ice. The particle will be retarded and deposited and the ice will be deformed around it. This is a grain by grain or aggregate by aggregate deposited sediment (Boulton 1974).

b) basal meltout till is produced at the base of a stagnant body of ice melting from below. This process is very slow. The geothermal heat can only melt about 6 mm of ice yearly per unit area (Paterson 1969). The speed of this process can be increased if flowing meltwater is introduced to the stagnant ice body.

c) diamicton with evidence of material being dropped into a subglacier cavity has theoretically been distinguished by Boulton (1982). However this type of till has not been distinguished in the investigation area.

2) Subaquatic environment. Diamictons deposited in a subaquatic environment have been described from many parts of the world (Dott 1963, Carter 1975, Evenson et al. 1977, May 1977, Gibbard 1980, Dreimanis 1982, Lewis et al. 1980, Gravenor and Rocha-Campos 1983, Gravenor et al. 1984, Eyles and Eyles 1983 and others) and from Precambrium to Holocene sediments (Domack 1982, 1983, Wright and Anderson 1982, Powell 1982, Orheim and Elverhøi 1981, Drewry and Cooper 1982). The terminology of diamicton deposited by sediment gravity flow in a subaquatic environment is very varied: debris flow according to Lowe (1979), waterlaid till Dreimanis (1976), subaquatic flow till Evenson et al. 1977, lacustro till May (1977), submarine flow till Hicock et al. (1981). Material melted out from the sole of a glacier and dropped to the bottom is called undermelt diamicton by Gravenor et al. (1984), subaquatic meltout till by Gibbard (1980), waterlaid till by May (1977), rain out material by Eyles and Eyles (1983).

For diamictons deposited by a sediment gravity flow process the term debris flow will be used according to Lowe (1976b, 1979) which is modified according to Middleton and Hampton (1973). In a debris flow the larger grains are supported by interstitial fluid and fine-grained particles, which have a finite yield strength. This means that the downslope movement is caused by internal shearing. When the force on the gravity flow diminishes at a critical point this force will be less than the yield strength of the debris flow and the whole flow freezes in situ (Carter 1975, Fisher 1971, Rodine and Johnson 1976, Middleton 1967).

There are two types of debris flow (Carter 1975, Lawson 1979) 1) The total thickness of the flow is involved in the shearing and 2) only a part of the vertical section of the flow is sheared. In this case a rigid plug exists in the upper part of the flow, (in a subaquatic environment the friction against

the water can shear of the surface of the debris flow (Carter 1975 after Middleton & Hampton 1973 and Johnson 1970)). In the parts of the debris flow where shearing occurs, clasts will show a preferred orientation with the long axes aligned in the direction of flow (Kurtz & Anderson 1979, Carter 1975, Enos 1977). According to Lewis et al. (1980) dispersive grain pressure (Bagnold 1956) acts on the particles in a debris flow. Larger clasts tend to be oriented with their long axes in the direction of the flow due to the impacts of smaller disoriented clasts (Lewis et al. 1980).

Because of the topography, (Fig. 3) the subaquatic deposits in the investigation area were deposited in a glaciolacustrine or lacustrine environment.

3) Subaerial environment. Two kinds of subaerially deposited diamictons can be distinguished: 1) Diamicton deposited by sediment gravity flows (Boulton 1968, 1972 a,b, Lawson 1979) and 2) supra glacial melt out till (Boulton 1970, Boulton and Deynoux 1981, Dreimanis 1976).

1) subaerial sediment gravity flow (flow till according to Hartshorn 1958, Boulton 1968, 1971, 1972, Boulton & Paul 1976 or debris flow according to Rodine & Johnson 1976) has been described in detail by Lawson (1979). Lawson distinguishes four flow types transitional to one another using the sediment gravity flow processes distinguished by Lowe (1976a, b).

In the geologic record it would be very difficult to distinguish between the different flow types (Lawson 1979) and no distinction is made in this work.

2) supra glacial meltout till (Boulton 1972 a,b) is produced when debris melts out on the surface of a glacier and deposits on the substrate without any detectable disturbances or displacements.

There are little diagnostic evidence of a subaerial environment but fossil ice-wedges are found in some places in the investigation area. The topset bed of a delta and widespread sandur sediments also indicate subaerial deposition or sedimentation in very shallow water.

4:6:2 Sand facies

Sediment gravity flow is common in the sand facies in the subaquatic environment. Five types of sedimentary processes can be distinguished: 1) turbidity currents (Kuenen & Migliorini 1950, Bouma 1962, Walker 1965, Ricci-Lucci 1975, Allen 1970, 1971), 2) Fluidized flow (Lowe 1976a, 1979), 3) Liquified flow (Lowe 1976a, 1979) and 4) grain flow (Lowe 1976b, 1979).

a) turbidity currents or density undercurrent (Powell 1982, Gustavson 1975, Gustavson et al. 1975, Smith et al. 1982) is caused by a current with a higher density than the ambient fluid. The term turbidity current is used according to Lowe (1976b) and Middleton 1966a, b, 1967). In a turbidity current particles are held in suspension by the turbulence of the fluid. According to Middleton (1967) turbidity currents can be divided into low concentration and high concentration currents. Low concentration flows give thin laminae usually normally graded. High con-

centration turbidity currents give a massive or reversed graded lower part of the bed and an upper normal graded part. In high concentration flows, part of the grain support comes from particle to particle interaction or dispersive grain pressure (Bagnold 1956, Carter 1975, Lowe 1976a, b, 1979, Lewis et al. 1980).

b) fluidized flow is used according to Lowe (1976a). The particles are fully supported (fluidized) by upward moving fluid (escaping pore fluid). This process is responsible for most of the water escape structures, like pseudo nodules, flame structures, and dish structures (Lowe 1975, Lowe and Lopicollo 1974).

c) liquified flows is used according to Lowe (1976a and 1979). "Liquified flows in which the sediment is not fully supported by the settling through its pore fluid, which is displaced upwards". This type of flow is laminar and occurs in well sorted sand and gravel. Suggested travel distances for liquified flows in fine sand is a kilometer or less, and for coarse sand resedimentation will take place within a few meters. The flow is triggered either by failure due to undercutting, oversteepening, a shock from a stormwave etc.

d) grain flow is used according to Lowe (1976a). The term grain flow is restricted to sediment gravity flow, in which dispersion of cohesionless grains is maintained against

gravity by grain dispersive pressure (Bagnold 1956) and in which the fluid interstitial to the grains is the same as the ambient fluid. A density modified grainflow (Lowe 1976a) is distinguished by the interstitial fluid having a different density (including dispersed fines) than the ambient fluid. This type of flow can be very common in glaciofluvial and glaciolacustrine sediments, which usually have a fine tail. Other kinds of modified flow also occur (Lowe 1976a, 1979).

4:6:3 The fine grained facies

The fine grained facies in the Jönköping area consist of laminated or massive clay and silt with thin laminae of usually fine sand. Thin (0.01-0.3 m) laminae of diamicton are often interbedded in the fine-grained sediments. Dropstones and intraclast are commonly found in these facies. For topographical reasons (Fig. 3) the sediments in the Vättern basin were deposited in a glaciolacustrine environment. The clay and fine silt were deposited from suspension and the horizontally laminated coarse silt and fine sand were deposited from low concentration turbidity currents (Middleton 1967). The interbedded diamicton laminae are mainly debris flow deposits.

5 The stratigraphy in the Vättern basin

In the Vättern basin it is possible to distinguish different stratigraphic units according to texture, structures, stratigraphic position, rock fragment composition, paleocurrent directions, and other properties. The lower units are only visible in the bluffs along the shore of lake Vättern.

To simplify the text each unit is given a name according to Hedberg (1976), but lower case letters are used because the stratigraphy is not formal. The common properties of each unit are presented below, starting from the lowest unit. The stratigraphy of the Vättern basin is presented in Fig. 16.

5:1 Methods of stratigraphic correlation

The stratigraphic correlation of the area is based on following ordered criteria:

- 1) stratigraphic position
- 2) inferred depositional environment
- 3) paleocurrent direction
- 4) rock fragment composition
- 5) geographical position
- 6) structures
- 7) texture
- 8) colour

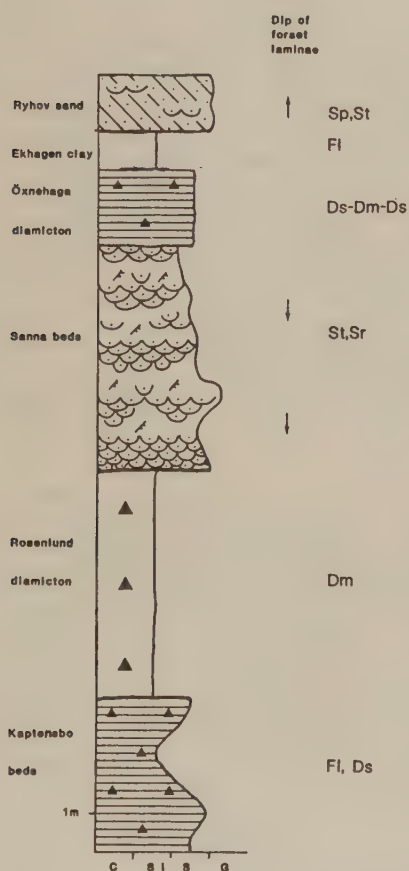


Fig. 16. A hypothetical stratigraphic column from the lower Vättern basin, with symbols and facies code (fig. 15). Arrows show the direction of foreset laminae.

9) degree of consolidation

The regional occurrence at low levels and the characteristic properties of the Rosenlund diamicton, makes this unit a key to the stratigraphy in the area. The distinguishing properties of the Rosenlund diamicton are the homogeneous appearance, the very high content of silt, the high content of Visingsö Group of Rocks in the rock fragment composition, the symmetrical jointing of the unit, and the regional distribution.

The Kaptensbo beds are found below the Rosenlund diamicton. This unit shows evidence of glaciolacustrine deposition. The unit is distinguished by the stratigraphic position below the Rosenlund diamicton, deformed horizontally laminated sediments, a great variation of lithofacies and the dropstones.

The Sanna beds are usually found on top of the Rosenlund diamicton. The Sanna beds are deposited in a glaciofluvial or glaciolacustrine environment. The unit is distinguished by the stratigraphic position and that the paleocurrent in the glaciofluvial units is directed towards a southern sector.

The Öxnehaga diamicton is superimposing the Sanna beds. The stratigraphic position is the most distinguishing property of the unit. Other properties are, the red colour, the low degree of consolidation and the heterogeneous grain size composition. The grain size composition of the unit usually reflects the underlying sediments, but is mostly somewhat coarser. The rock fragment composition usually shows a lower content of Visingsö Group of Rocks than the Rosenlund diamicton from the same site shows.

The Ekhagen clay is superimposing the Öxnehaga diamicton. The stratigraphic position and the grain size composition are the distinguishing properties of this unit.

The Ryhov sand is superimposing the Ekhagen clay. The unit is distinguished by the stratigraphic position and the paleocurrent towards the northern sector. In the area this unit is not found above +120 m. Above +120 m this unit corresponds to erosional landforms. To ascertain correlations between different sites, it is necessary to have more than one stratigraphic unit at the site. Correlations to a site with only one stratigraphic unit, is always uncertain unless physical tracings between sites are possible.

5:2 The Kaptensbo beds

The Kaptensbo beds are only visible in the bluffs between Vilhelmsro and Kaptensbo north of Jönköping. The total thickness of the unit is not known but it exceeds 20 m. The Kaptensbo beds consist of horizontally laminated sand, silt, clay and diamicton (Fig. 17). Deformed small-scale cross-laminated sand and silt is occasionally found. Clasts bigger than cobbles are uncommon. Intraclasts of sand, silt, clay or clayey diamicton have been observed.

The lamination is often contorted. Load- and waterescape-structures are commonly found in the unit (Fig. 18). Folds and faults of different sizes and shapes are found in most parts of the unit. The lamination under big-



Fig. 17. The Kaptensbo beds in section 7 at Vilhelmsro.

ger clasts, including intraclasts, is usually deformed.

The rock fragment composition of the diamicton units in the Kaptensbo beds is about 70 % of Visingsö Group of Rocks and 30 % of crystalline rocks.

5:3 The Rosenlund diamicton

The Rosenlund diamicton is not found on the surface, but it is commonly found in the bluffs along lake Vättern. The maximum thickness of the unit is not known, but it exceeds 30 m.

The Rosenlund diamicton has a characteristically bluish gray colour.

The grain-size composition is usually homogeneous within the individual site and between sites. There are very small differences from sample to sample. Localities far from each other can show some differences. The clay content varies between 10-30 %, the silt- between 40-60 % and the sand- between 5-30 %. Clasts are few but up to boulder size occur. The clasts usually show a high degree of roundness. Clasts are usually striated.

The Rosenlund diamicton is usually massive. Lenses of sorted sediments are very uncommon in the unit. In low topographic positions the Rosenlund diamicton sometimes has an interbedded upper contact.

The Rosenlund diamicton is usually jointed in

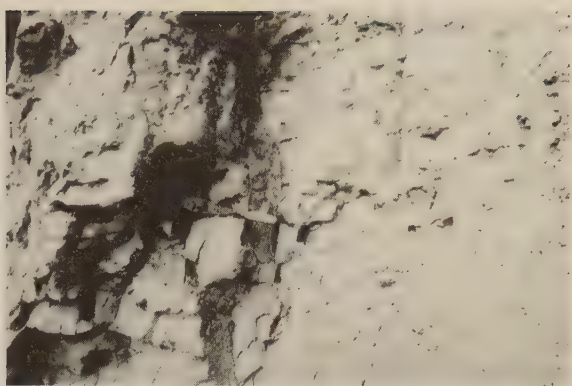


Fig. 18. The Rosenlund diamicton.

a subhorizontal and a subvertical system (Fig. 19). At one site there is evidence of the whole unit being displaced. At another site there are deformation structures in the contact to overlying sediments. At Rosenlunds bankar fluvial erosion has cut trenches in the Rosenlund diamicton. The trenches are up to 25 m deep. In the lower contact, deformation structures are found in underlying sediments.

The rock fragment composition varies between 80-95 % of Visingsö Group of Rocks and 5-20 % of crystalline rocks. The lowest percentages of Visingsö Group of Rocks are found in the northwestern part of the investigation area.

5:4 The Sanna beds

The Sanna beds are seldom found on the surface. The unit is best observed at Rosenlunds bankar (fig 20). The maximum thickness is not known but it exceeds 35 m. In the Tenhult valley there are indications of a thickness of more than 50 m.

The Sanna beds consist of gravel, sand, silt, clay and diamicton. Clasts bigger than cobbles are not found, but both big and small intraclasts are common. The gravel in the unit is planar- or trough-bedded, and horizontally or cross-laminated. The sand displays planar or trough-bedding with horizontal, cross- or small-scale cross-lamination. The silt is planar bedded. It is



Fig. 19. Deformation structures in the Kaptensbo beds at Kaptensbo.



Fig. 20. The Sanna beds at Rosenlund.

massive, draped or horizontally laminated. The clay beds are thin either massive or horizontally laminated. In the upper parts of the Sanna beds thin beds of diamicton occur. The diamicton beds are either massive or stratified. The sediments are often contorted.

The rock fragment composition is about 80 % of Visingsö Group Rocks and 20 % of crystal-

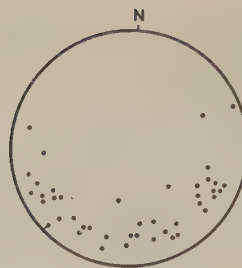


Fig. 21. The direction of dip in planar- and trough-bedded cross-laminated sand and gravel in the Sanna beds at Rosenlund.

line rocks.

The fluvial transported sediments show a paleocurrent towards the south (Fig. 21).

5:5 The Öxnehaga diamicton

The Öxnehaga diamicton is often found on the surface along the shores of lake Vättern. The thickness of the bed varies between 0-7 m. The Öxnehaga diamicton is usually red or reddish brown.

The Öxnehaga diamicton usually consists of many beds of diamicton, separated by units of laminated sediments.

The grain-size composition is heterogeneous



Fig. 22. The Ryhov sand.

and often reflects the grain-size composition of underlying sediments. The Öxnehaga diamiction is usually massive, but stratified beds occur. Lenses and thin beds of sorted sediment are common. Interbedded sorted sediments are often folded or faulted. Big folds, including the main part of the unit, are also observed. At many sections, underlying sorted sediments are picked up and incorporated into overlying diamiction unit. Grading and interbedded contacts between underlying sorted sediments and overlying diamiction units are also observed.

The rock fragment composition is heterogeneous both within and between sites and sections and varies between 62-82 % of Visingsö Group of Rocks, with a mean of 73 %, and 18-38 % of crystalline rocks.

5:6 The Ekhagen clay

The Öxnehaga diamiction grades into the Ek-

hagen clay. The Ekhagen clay is found on the surface in many places, for instance, in the Tenhult valley, in Landsjödalen valley, the eastern parts of Jönköping etc. The thickness of the unit varies between 0.5-8 m.

The Ekhagen clay consists of massive or rhythmically laminated clay and silt. Thin beds of sand and diamiction occasionally occur.

5:7 The Ryhov sand

The Ryhov sand is found at Ryhov, west of lake Rocksjön, at Väster in Jönköping, northeast of Bankeryd and at Tokeryd. The maximum thickness of the bed is not known, but it exceeds 10 m. Drillings at Väster in Jönköping suggest a thickness of about 50 m. The unit consists of planar- and trough-bedded cross-laminated gravel and sand, horizontally and small-scale cross-laminated sand (Fig. 22).

6 Glacial morphology

A geomorphological map over the investigation area is presented in an earlier paper (Waldemarson 1979, 1981). The geomorphology of certain areas is presented in earlier works (Waldemarson 1983, Bjelm 1976).

6:1 Erosional landforms

As described in chapter 2, the morphology in the investigation area is related to the morphology of the basement. During the glacial events the basement was eroded by glaciers. Particles of the substratum were removed by crushing (Boulton 1982), and eroded by plucking (Boulton 1972) or by grinding (Haldorsen 1981). These erosional processes give the landscape different morphology types, which sometimes can be seen in the investigation area. The plucking and crushing produce the rugged lee sides of many hills like Taberg, Hultängskullen and Bondberget. On a smaller scale the processes can be seen on the lee side of the whale-back knobs on the northern shore of lake Landsjön (Fig. 23). If the crushing is incomplete, different kinds of chattermarks occur. Chattermarks especially crescentic fractures are commonly found in the area.

The abrasion between particles stuck in the sole of the glacier and the substratum, produced the polished cliffs and eroded the striae in the basement (Fig. 23). Striae directions of the investigation area are

shown in Fig. 24. A special investigation of striae in Landsjö dalen valley is presented in Fig. 137. In this investigation two systems of striae were found, one system showing direction from north and northeast and another showing striae from a western sector. Striae in the northern or northeastern sector were found everywhere and at any altitude in the studied area, while the striae in the western sector were not found above +230 and not east of Skärstad. The striae in the western sector are younger than those from north or northeast.

On the western side of the Vättern basin there are two sets of striae. One set is from a northern sector and the other from an eastern sector (Fig. 137). The age relation between the two systems is not clear but there are indications that the eastern system is younger than the northern system (Chapter 10).

In the Vättern basin and in the slopes the morphology of the unconsolidated sediments is dominated by erosional landforms. The systems of ravines (Waldemarson 1981 and 1983) in the slopes of the Vättern basin are of fluvial origin. Most of the ravines were probably formed just after the drainage of the elevated glacial lakes in the Vättern basin, when the sediments were soaked and not covered by vegetation.



Fig. 23. A bedrock knob on the northern side of lake Landsjön. The picture was taken towards the southeast.

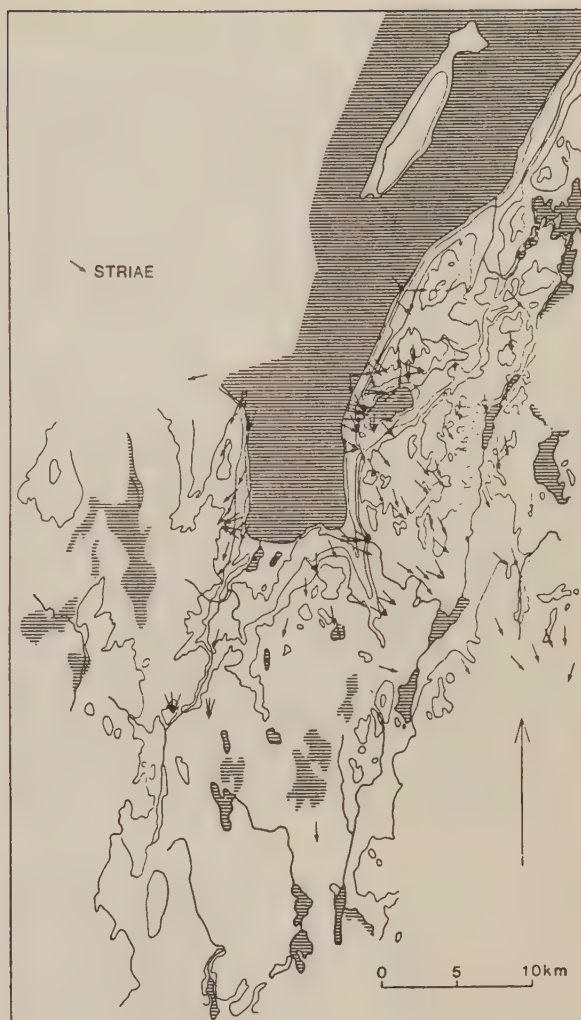
6:2 Depositional landforms

South of the threshold area there are landforms, formed by depositional processes in sand and gravel. The area displays an ice-contact morphology. The landforms consist of mounds, plateaux, short ridges and kettle holes. The internal stratification shows slump structures formed when ice-support disappeared.

Southwest of Tenhult there is an area of drumlins of crag and tail type (Chamberlin 1894). The area was briefly investigated by Bjelm (1976). The long axes of the drumlins are in the same direction as the striae in the area.

A study of the morphology of Rosenlunds bankar and a nautic chart of the southern parts of Lake Vättern suggest that the hill with Rosenlunds bankar is an eroded drumlin.

Fig. 24. The striae in the investigation area. The map is a compilation from Munthe and Sandegren (1907), Gejer et al (1951), Bjelm (1976), Svantesson (1985) and own observations.



7 Sites below +130 m in the Vättern basin

In this subarea all sites in the shore zone of lake Vättern are included (Fig. 25). In most of the described sections the characteristic Rosenlund diamicton is present. This type of diamicton has been found only at one place outside this subarea (at Samset about 3 km southwest of Jönköping and at about +200 m). Most of the sites are shore cliffs with long continuous sections (Fig. 26).

7:1 Rosenlunds bankar

Rosenlunds bankar is a shore bluff, about 2.3 km long, roughly trending in east northeast (Fig. 27). The maximum height is about 40 m above the lake level (+88.5). The cliffs are kept open by wave action from the transgrading lake (Norrman 1964). A combination of information from bathymetric maps, topographic maps, airphotos and field studies indicates that the Rosenlunds bankar is a section through a drumlin-shaped hill. The northern part of the drumlin has been eroded by the transgrading lake and only a shallow bank running 10°-180° remains in the lake (Piper et al. 1983). In the eastern parts of the bluff there was a long fresh cut during my investigation. In the western parts only

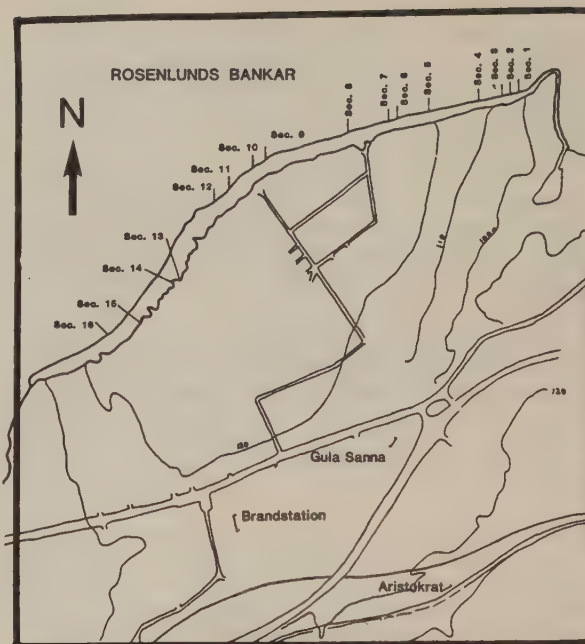


Fig. 26. Topographic map of Rosenlunds bankar.

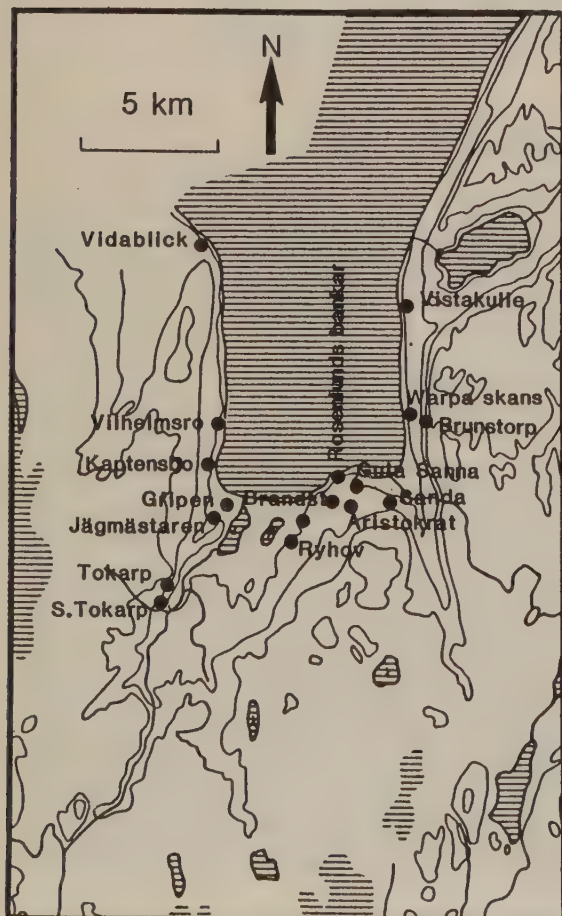


Fig. 25. Investigated sites in the lower part of the Vättern basin.

small sections were free from scree or vegetation. The survey of the eastern part of Rosenlunds bankar is shown in Figs. 28 and 29.

7:1:1 General description

In the lower part of the site there is a silty clay diamicton, called the **Rosenlund diamicton**. It is 0-35 m thick and has an erosive upper surface. Flowing water eroded trenches more than 25 m deep in the cohesive diamicton.

The Rosenlund diamicton is superimposed by the **Sanna beds**. The Sanna beds consist of sand, gravel, silt and clay. Trough-bedded sand dominates, but small-scale cross-laminated sand and horizontally laminated sand is also common. The gravel is massive, horizontally- or trough-bedded and is found in lenses less than 100 m long and not exceeding 2 m in thickness. The silt is massive horizontally laminated or small-scale cross-laminated (type-B and sinusoidal ripples). Clay is found as thin laminae over sinusoidal ripples or rhythmically laminated or thick massive units, up to 0.1 m. In the upper part of the Sanna beds thin laminae of sandy diamicton have been found.

Lumps, balls and slabs of diamicton more than 2 m thick and 20 m long as well as smaller ones are often found in the Sanna beds. The contact with the overlying diamicton is always very complicated, with interfingering sand and diamicton beds (interbedded contact), sand grading into diamicton, sand being incorporated into the diamicton and folding and faulting of lenses and laminae. The Sanna beds are superimposed by the **Örnehaga diamicton**. The Örnehaga diamicton is by nature red or redbrown and sandy. It is

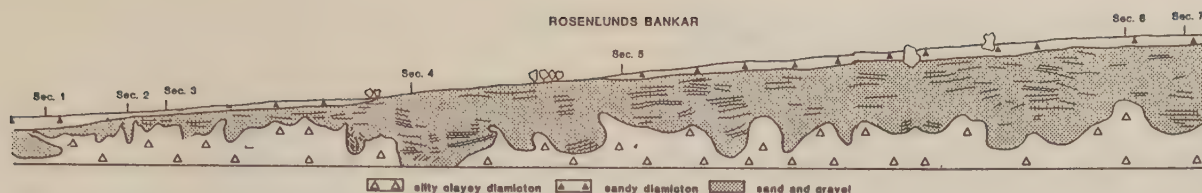


Fig. 27. The eastern part of Rosenlunds bankar.

usually unconsolidated and contains few clasts. The clasts are usually rounded and are often striated. The Öxnehaga diamicton is superimposed by the Ekhagen clay. The Ekhagen clay consists of rhythmically laminated clay or massive, often poorly sorted clay.

7:1:2 Sections

It has not been possible to do a detailed investigation of the entire cliff. Instead, nine long and six shorter sections are described and supplemented with scattered observations in the bluff.

The sections are described from the level of lake Vättern (+88.5 m) and from east to west. The lithofacies code (see methods) for the units are presented in brackets.

Comments are added to some sections when there is information of special interest or information relevant only to the particular section.

Section 1

The section is situated in the easternmost part of the Rosenlunds bankar (Figs. 26 and 27). The section starts at the level of lake Vättern (+88.5 m) and is described from bottom to top (Fig. 29).

0.9 m gray silty clayey diamicton (Dm). It is consolidated and jointed with iron- and manganese oxides precipitated in the fractures.

0.6 m gray laminated silt (F1).

0.45 m contorted horizontally laminated sand (Sh).

0.5 m small-scale cross-laminated sand and silt (Sr) (mainly type-B and sinusoidal ripples). There are 10 sequences of type-B ripples grading into sinusoidal ripples. The bed is fining upwards.

0.25 m bluish gray silty clayey diamicton (Dm). The bed tapers to the east. The unit is part of underlying diamicton.

0.8 m trough-bedded cross-laminated sand and small-scale cross-laminated sand (St,Sr). There is a number of intraclasts of silt, clay and diamicton. Foreset laminae of the ripples dip towards the east.

0.25 m laminated silt and fine sand (F1). In the top of the bed there are sinusoidal ripples and horizontally laminated sand (Sr, Sh). The bed is coarsening upwards. The laminae are dipping 20° towards 181° .

0.95 m trough bedded cross-laminated sand with tangential lower contact and small scale cross-laminated sand (St,Sr). The cross-laminated sand has a tangential lower contact. The small-scale cross-lamination is mainly type A ripples. The foreset laminae of the ripples dip towards the east.

0.6 m small-scale cross-laminated sand and silt (Sr). The unit consists mainly of type B ripples and sinusoidal ripples. There are about 0.2 m between each set of sinusoidal ripples. The bed is dipping 53° to 186° , indicating that the bed is tilted.

0.95 m gray silty clayey diamicton (Dm). It is jointed.

1.3 m laminated very fine sand and silt (F1). In the top of the bed there are some sets of sinusoidal ripples (Sr). The laminae are dipping 37° towards 203° in the lower part of the bed and 42° towards 239° in the upper part.



Fig. 28. The eastern part of Rosenlunds bankar, the picture is taken approximately towards the south.

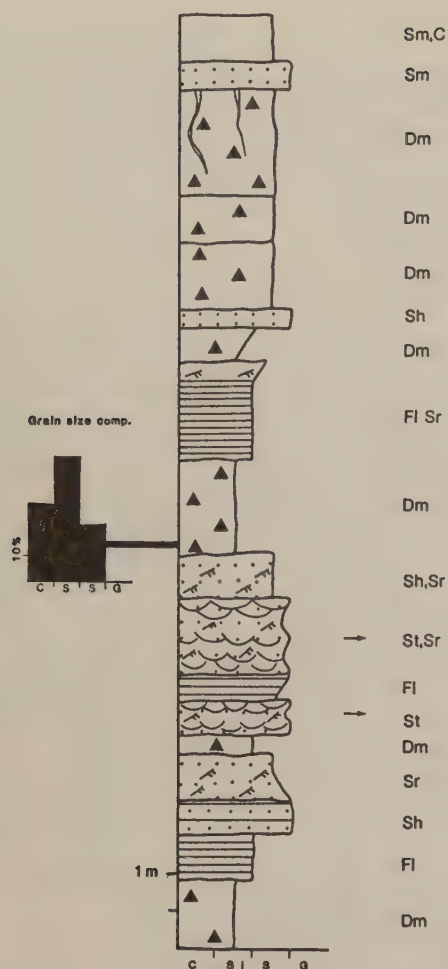


Fig. 29. Log of section 1 at Rosenlund.

0.45 m gray silty clayey diamicton (Dm). Upwards, the diamicton becomes more coarse-grained (reversed graded). It is jointed.

0.25 m horizontally laminated sand (Sh). The bed is faulted in the lower part.

0.9 m reddish gray sandy diamicton (Dm). The bed is jointed and contains a number of lenses of sand and silt. Clasts are clustered in the lower part of the bed. The lower boundary is sharp, but the upper is graded in a 1-2 cm thick zone. In the vicinity of the contact zone, there are many lenses of sand.

0.6 m redbrown sandy diamicton (Dm). The diamicton is very unconsolidated.

1.4 m redbrown clayey sandy diamicton (Dm). There are subvertical winding veins of white or greenish white clayey sandy diamicton.

0.4 m massive gravely sand (Sm).

0.6 massive gravely sand with organic material.

Section 2

Section 2 is situated about 25 m west of section 1 (Figs. 26 and 27). The section starts at the level of lake Vättern (+88.5 m, Fig 30).

12 m bluish gray silty clay diamicton (Dm). The diamicton is very consolidated and jointed with iron- and manganese oxides precipitated in the fractures.

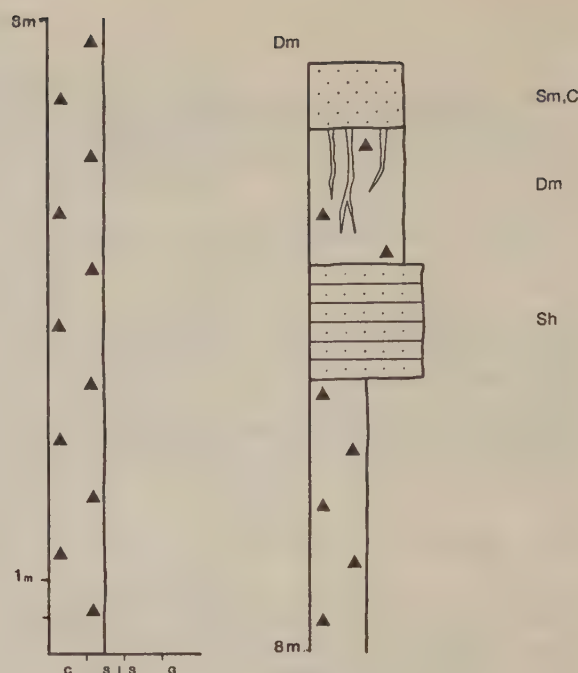


Fig. 30. Log of section 2 at Rosenlund.

1.5 m horizontally laminated sand (Sh). The lamination is very disturbed by faulting. The bed is almost surrounded by the underlying diamicton.

1.8 m redbrown sandy diamicton (Dm). There are thin subvertical winding veins of clayey sandy diamicton.

0.9 m fine sand and silt with organic material (Fm,C).

Comments to section 2

The faulting of the horizontally laminated sand is due to the sand sinking into the silty clay diamicton. This indicates that the diamicton was plastic when the sand was deposited.

Section 3

Section 3 is situated about 50 m west of section 1 (Figs. 26 and 27). The section starts at the level of lake Vättern (+88.5 m, Fig. 31).

12 m scree.

3.0 m gray silty clay diamicton (Dm). It is jointed.

1.2 m reddish gray sandy diamicton (Dm). There are many lenses and thin beds of silt and sand.

0.05 m red clayey sandy diamicton (Dm).

0.03 m red sandy diamicton (Dm).

0.02 m laminated clayey silt (Fl).

0.3 m laminated fine sand with thin laminae of silt (Sh).

0.02 m laminated clayey silt (Fl).

0.5 m redbrown sandy diamicton (Dm) with thin subvertical veins of white clayey sandy diamicton.

0.7 m yellowish gray stratified sandy diamicton (Ds). The bed displays a higher clast content than the other diamicton beds. Clasts are rounded or well rounded.

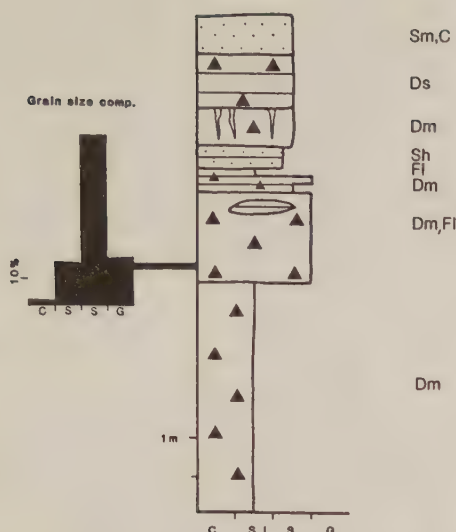


Fig. 31. Log of section 3 at Rosenlund.

0.5 m massive sand with organic material (Sm, C).

Section 4

Section 4 is situated about 135 m west of section 1 (Figs. 26 and 27). The section starts at the level of lake Vättern (+88.5 m Fig. 32).

12.2 m alternating units of trough-bedded cross-laminated sand and small-scale cross-laminated sand and silt (St,Sr). The small-scale cross-laminated sand and silt consist mainly of 0.2 m thick sets of type-B ripples, grading into sinusoidal ripples. About 6 m up in the unit, the bedding plane is dipping 4° towards 90°. About 4 m up in the bed there are type-A ripples laterally grading into planar-bedded cross-laminated sand. The foreset laminae in this unit are dipping 11° towards 279°. About 1.5 m up in the bed the foreset laminae in the trough-bedded cross-laminated sand are dipping 17° towards 222°, in the same level about 10 m to the west the foreset laminae are dipping 43° towards 111°. 1.8 m up in the bed the foreset laminae are dipping 34° towards 115° and 2.3 m up 24° towards 202°. 9.2 m above the bottom of the bed the foreset laminae are dipping 36° towards 168°, about 9.5 m up 33° towards 157°. 10 m east of the last reading the foreset laminae in trough-bedded cross-laminated sand is dipping 26° towards 214°. The lower part of this bed was deposited in a narrow trench in the underlying silty clayey diamicton (Figs. 27 and 28). The eastern wall of the trench dips 72° towards the west and strikes 23-203°, the western wall 70° towards the northeast and strikes 136-316°. The sediment displays no disturbances in the contact with the diamicton. In the lateral contact between the laminated sand and the diamicton it is possible to see how lumps of the diamicton have been eroded by the undercutting of the walls and how the intraclasts are incorporated in the laminated sand. The pebble size

intraclasts are angular and unarmoured. They are of the same size as the cubes in the surrounding jointed diamicton, (suggesting the diamicton was jointed when the trench was eroded). There is no erosional lag in the boundary between the sand and the diamicton. 3.5 m trough-bedded cross-laminated sandy pebbly gravel (Gt).

There is a number of unarmoured clasts of silty clay diamicton in the bed, otherwise black shale is dominating the rock fragment composition. Clasts are imbricated towards the northwestern sector. The foreset laminae are dipping 20° towards 161°.

0.95 m planar-bedded cross-laminated sand

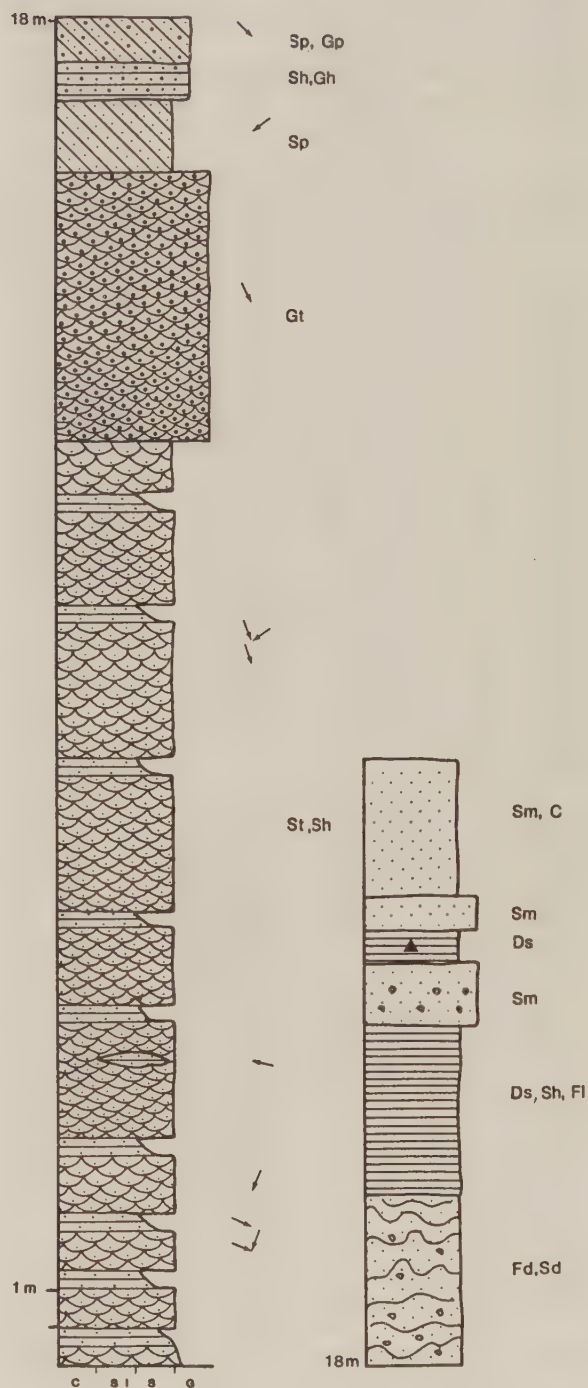


Fig. 32. Log of section 4 at Rosenlund.

(Sp). The laminae are dipping 10° towards 236° .

0.5 m horizontally laminated sand and gravel (Sh, Gh). Black shale dominates the rock fragment composition.

0.6 m planar-bedded cross-laminated sand and gravel (Sp, Gp). The clasts are usually disc shaped and of black shale. The laminae are dipping 25° towards 126° .

2.2 m contorted sand and silt (Sd, Pd). There are lumps of silty clayey diamicton in the unit. The size of the intraclasts varies between 1-50 cm. No primary stratification is possible to identify.

2.2 m alternating beds of stratified sandy diamicton laminated silt and sand (Ds, Fl, Sh). The sand and silt are horizontally laminated except in one bed of type-B ripples sand. The stratification is disturbed in the upper part of the unit.

0.8 m massive poorly sorted sand (Sm). The sand is dark brown, due to secondary

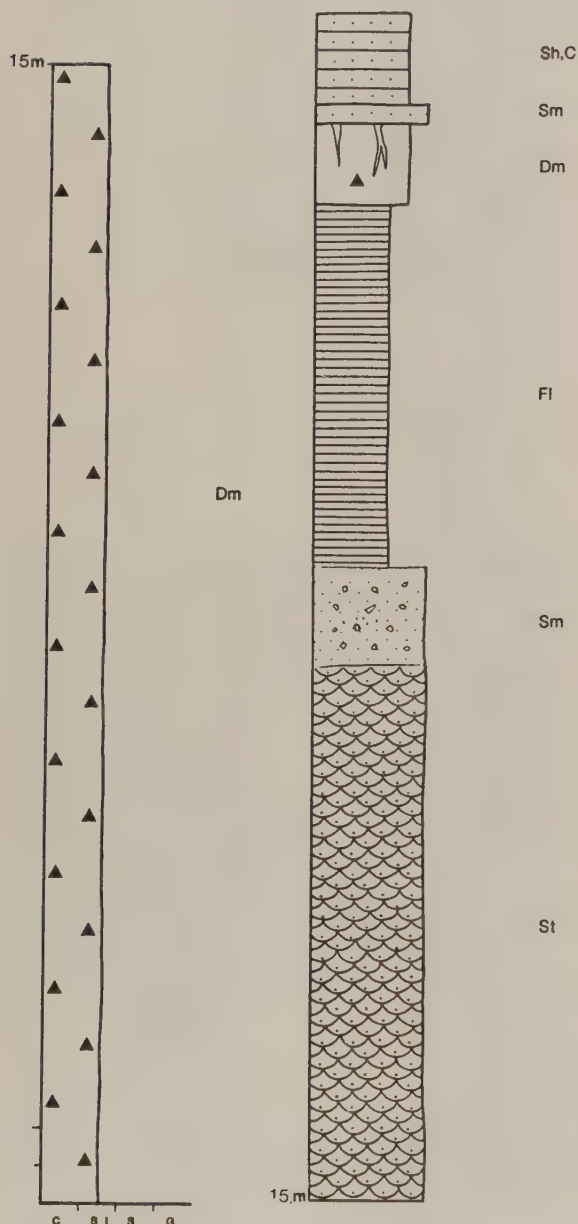


Fig. 33. Log of section 5 at Rosenlund.

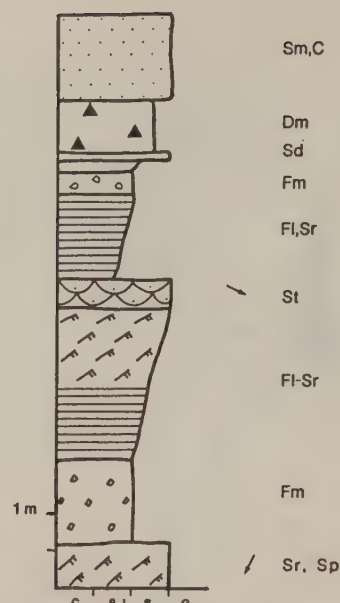


Fig. 34. Log of section 6 at Rosenlund.

processes (enrichment of iron- and manganese oxides). There are many pellets of redbrown sandy diamicton in the sand. There are laminae of silt in the bed.

0.45 m stratified sandy silty diamicton (Ds). It is redbrown with light gray winding veins of clayey sandy diamicton. The texture is heterogeneous and there are several lenses of sand and silt in the bed. There is a grading upper contact.

0.45 m massive sand (Sm). Some gravel particles occur in the unit. There is an enrichment of gravel in the lower contact zone.

1.8 m fine sand and silt with organic material (Sm,C).

Section 5

Section 5 is situated about 300 m west of section 1 (Figs. 26 and 27). The section starts at the level of lake Vättern (+88.5 m) (Fig. 33).

15 m silty clayey diamicton (Dm). The diamicton is jointed, with iron- and manganese oxides precipitated in the fractures.

7 m trough-bedded cross-laminated sand (St). The lamination is disturbed by minor faulting.

1.3 m massive sand (Sm). There are lenses of silty clayey diamicton in the unit. There are many intraclasts of silty clay diamicton.

4.8 m yellowish gray laminated silt with thin laminae of fine sand (Fl). In the bed there are several reddish bands. There is no difference in texture between the gray and the red parts of the bed.

1.05 m redbrown sandy diamicton (Dm). There are light gray thin subvertical winding veins of clayey diamicton. There are thick lenses of stratified sand in the bed.

0.25 m massive sand (Sm). Pebbles occur in the unit.

1.2 m stratified fine sand and silt with organic content.

About 50 m west of section 5 there is a big trench in the Rosenlund diamicton. The bottom

of the trench is about 5 m above the level of lake Vättern (+88.5 m). There is no erosional lag in the bottom of the trench. The trench is filled mainly with trough-bedded cross-laminated gravely sand. The gravel-size particles are often intraclasts of silty clayey diamicton.

Near the bottom of the trench there is a number of small faults, with a displacement of about 0,01 m. The fault fractures are filled with structureless sand. In a perpendicular wall there are faults of the same size, but the fractures are filled with massive clay.

Section 6

Section 6 is situated about 400 m west of section 1 and about 150 m east of the big trench, in the eastern part of Rosenlunds bankar (Fig. 26 and 27). The section starts about 29 m above the level of lake Vättern (+88.5 m, Fig. 34).

0.6 m type-A ripples sand laterally grading into planar laminated sand (Sr,Sp). The foreset laminae are dipping 22° towards 205° .
1.1 m redbrown massive fine silt (Fm).

2.0 m horizontally laminated silt coarsening upwards into sinusoidal and type-B ripples sand (Fl--Sr). The sediment is yellow except for some red fine-grained laminae.

0.4 m trough-bedded cross-laminated sand (St). In the bed there is a thin fracture filled with silt and clay. The fracture dips 57° towards the west and is striking $0-180^\circ$. The foreset laminae in the cross-laminated sand dips 19° towards 116° .

1.2 m horizontally laminated silt and some small-scale cross-laminated silt and sand (Fl,Sr). There are some thin laminae of red clay in the bed. The clay laminae are more frequent in the lower part of the bed. In the lower part there are also some thin laminae of red sandy diamicton. The unit is roughly a coarsening upward sequence.

0.3 m massive red silt with thin winding beds of red clay (Fm). There are many clasts and intraclasts in the unit. The intraclasts consist of balls of clay or sand.

0.15 m red or yellow horizontally laminated very fine sand and silt (Fl).

0.1 m contorted fine and medium sand (Sd).

0.7 m redbrown sandy diamicton (Dm). There are light gray subvertical winding veins of clayey diamicton in the unit.

1.1 m massive fine sand and silt with organic material (Sm,C).

Section 7

Section 7 is situated about 25 m west of section 6 (Figs. 26 and 27). The section starts at the level of lake Vättern (+88.5 m, Fig. 35).

6.3 m dark gray silty clayey diamicton (Dm). It is jointed. The upper contact is erosive.

6.1 m trough-bedded cross-laminated sand (St). In the lower part of the bed there are some faults. The main fault dips 86° towards the north and strikes $104-284^\circ$. About 1 m up in the unit the foreset laminae are dipping 53° towards 132° , about 1.5 m up, 29° towards 107° and 4.6 m up in the unit 6° towards 62° . The lamination is disturbed in the top of the unit.

0.9 m horizontally laminated sand (Sh). There

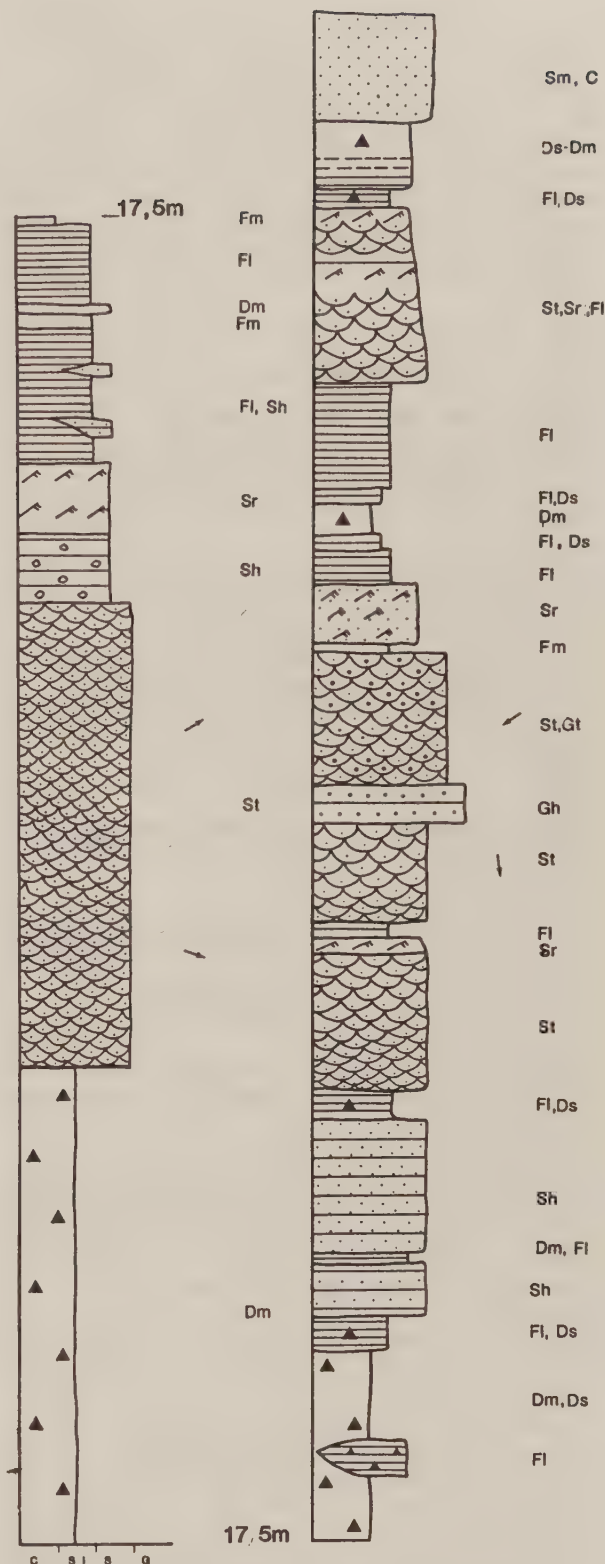


Fig. 35. Log of section 7 at Rosenlund.

are intraclasts of clay and silty clay diamicton in the unit. There are some winding veins of clay in the unit.

0.9 m small-scale cross-laminated sand and silt (Sr). Type-B ripples dominate.

1.8 m horizontally laminated silt (Fl). There are lenses of sand in the unit.

0.2 m massive bluish gray silt (Fm).

0.1 m redbrown diamicton (Dm). The unit is jointed.

0.8 m horizontally laminated silt (Fl).

0.1 m massive red clay (Fm).

2.6 m silty clay diamicton (Dm). The color varies from redbrown to bluish gray. The diamicton is jointed, with iron and manganese oxides precipitated in the fractures. In the middle of the bed there is a 0.5 m thick lens of stratified sandy silty diamicton interbedded with thin laminae of silt and clay (Fl).

0.45 m laminated clay, silt and diamicton (Fl, Ds).

0.7 m contorted horizontally laminated sand (Sh).

0.15 m gray silty sandy diamicton (Dm) with thin laminae of silt and clay (Fl).

1.6 m horizontally laminated sand (Sh).

0.4 m laminated silt, clay and silty sandy diamicton (Fl, Ds). There are some dropstones in the unit.

1.8 m trough-bedded cross-laminated sand, slightly disturbed (St). There are very contorted silt laminae in the bed. Intraclasts of silt have been found in the unit.

0.2 m small-scale cross-laminated sand (Sr).

0.2 m laminated silt and clay (Fl).

1.3 m trough-bedded cross-laminated sand (St). The foreset laminae are dipping 26° towards 174° .

0.5 m horizontally laminated pebbly gravel (Gh).

1.8 m trough-bedded cross-laminated sand and gravel (St, Gt). The foreset laminae are dipping 19° towards 238° .

0.1 m massive silt (Fm).

0.8 m small-scale cross-laminated sand (Sr). In the top of the unit there are some draped laminae of silt.

0.45 m contorted laminated silt (Fl).

0.2 m laminated silt, clay and silty diamicton (Fl, Ds).

0.4 m massive silty clay diamicton (Dm).

0.2 m laminated silt, clay and silty clayey diamicton (Fl).

1.4 m laminated silt (Fl).

2.8 m trough cross-laminated sand (St). There are some units of small-scale cross-laminated sand (Sr) and laminated silt (Fl). The lamination is slightly disturbed. The unit is a fining upward sequence. About 0.5 m up in the unit the foreset laminae are dipping 30° towards 120° .

0.25 m laminated coarse silt and fine sand with laminae of diamicton (Fl--Ds). The diamicton laminae become more frequent upwards. A sand lamina in the lower part of the bed shows boudinage structures.

0.9 m redbrown silty sandy diamicton. In the lower part of the bed the diamicton is stratified (Ds--Dm). There are many lenses of sand in the lower part of the bed. There are many light gray or greenish gray subvertical winding veins of clay in the diamicton. The clasts in the diamicton are often weathered.

1.4 m massive fine sand and silt with organic material (Sm,C).

Section 8

Section 8 is situated about 10 m west of the big trench in the eastern part of the Rosenlunds bankar and about 600 m west of section 1 (Figs. 26 and 27). The section starts at the level of lake Vättern (+88.5 m) (Fig. 36).

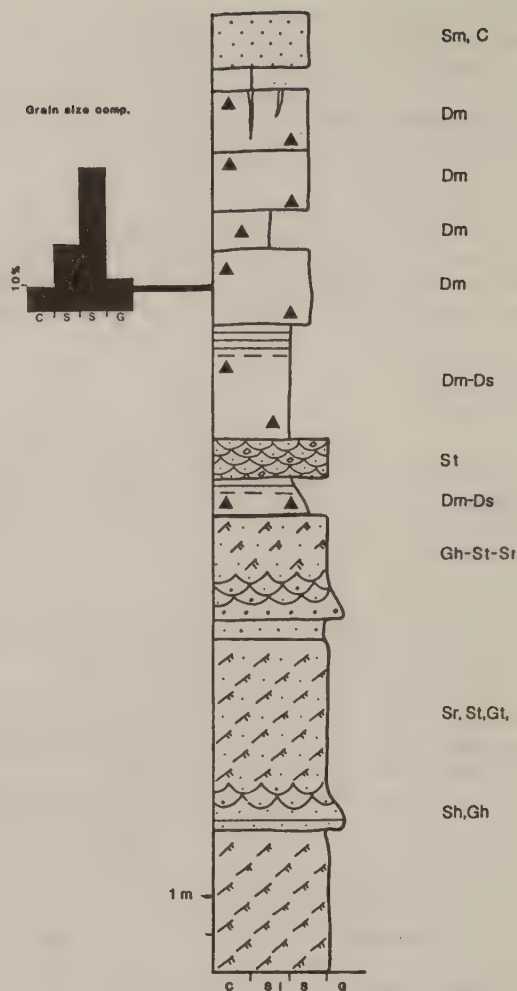


Fig. 36. Log of section 8 at Rosenlund.

24 m scree.

6 m small-scale cross-laminated sand (Sr). There are some units of horizontally laminated and trough-bedded cross-laminated sand and gravel (St, Gt, Sh, Gh). Minor faults are common in the unit. About 3 m up in the bed the foreset laminae in the trough-bedded cross-laminated sand are dipping 15° towards 147° .

0.5 m olive green sandy diamicton (Dm-Ds). In the top of the bed the diamicton is stratified with alternating laminae of sand and silt. The diamicton is fining upwards (normal graded). Underlying sand and gravel have been incorporated into the diamicton.

0.5 m olive green silty diamicton (Dm--Ds). It is compact but heterogeneous. In the top of the bed there are many lenses of redbrown sandy diamicton.

In the bed, there are cobble and boulder size clasts (in one case stratified) of red weathered sandstone. The diamicton is grading into overlying diamicton.

1 m redbrown sandy diamicton with few clasts (Dm).

0.5 m silty clayey diamicton (Dm). There is a relatively high clast content in the unit. The diamicton is heterogeneous, very compact and jointed.

0.8 m redbrown silty sandy diamicton (Dm). There are many lenses of sand and silt in the bed.

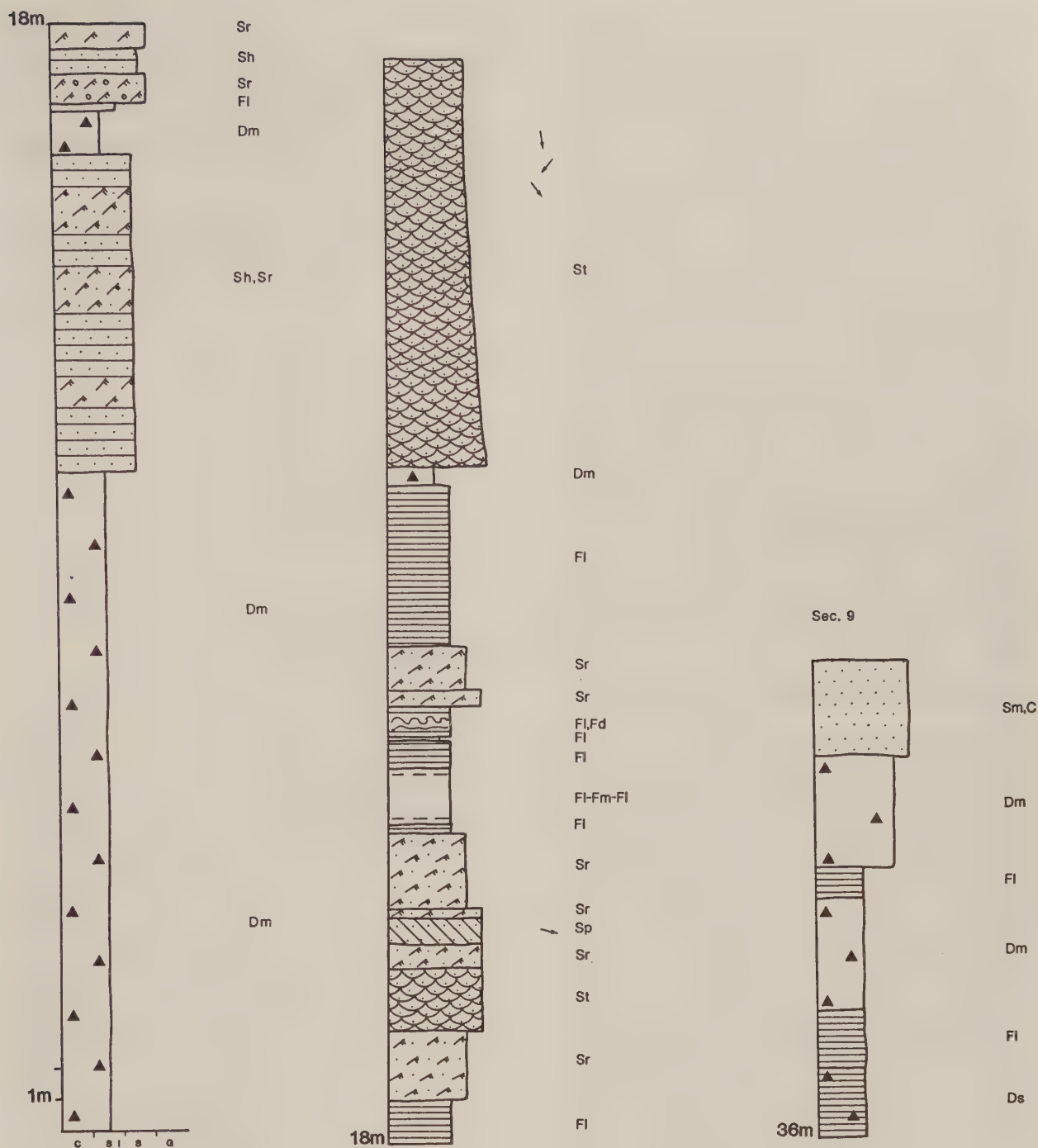


Fig. 37. Log of section 9 at Rosenlund.

0.8 m redbrown sandy diamicton (Dm). There are thin subvertical winding veins of light gray clay diamicton in the bed. The diamicton grades into overlying water-sorted clay.
 0.3 m gray poorly sorted clay (Fl).
 0.7 m massive sand and silt with organic material (Sm,C).

Section 9

Section 9 is situated about 850 m west of section 1 and about 270 m west of the big trench in the eastern part of Rosenlunds bankar (Fig. 26). The section starts at the

level of lake Vättern (+88.5 m, Fig. 37).

10.5 m bluish gray silty clayey diamicton (Dm). The diamicton is jointed.

5.0 m horizontally and small-scale cross-laminated sand and silt (Sh, Sr). The laminae are standing almost vertical except in the lowest part of the unit, where the lamination is contorted, folded and faulted.

0.7 m dark gray silty clayey diamicton (Dm). It is jointed and contains many lenses of sand.

0.1 m laminated silt and clay (Fl).

0.4 m small-scale cross-laminated sand (Sr). There are lumps of silty clay diamicton in the unit.

0.4 m horizontally laminated sand and coarse silt (Sh). The bed is rhythmically laminated with about 15 mm thick laminae of sand and 3 mm thick laminae of silt. The bed is dipping 13° towards 126°.

0.4 m small-scale cross-laminated sand (Sr). The bed is dipping 3° towards 139°.

0.7 m laminated coarse silt (Fl). The bed is dipping 3° towards 139°.

1.1 m small-scale cross-laminated fine sand (Sr). The bed consists of mainly very low type-B ripples (50 mm long and 10-15 mm high).

1.0 m trough-bedded cross-laminated sand (St). The foreset laminae are dipping 22° towards 190°.

0.4 m small-scale cross-laminated sand (Sr). The bed is dipping towards the south but the current ripples indicate a current towards the northwest.

0.4 m planar cross-laminated sand (Sp). The foreset laminae are dipping 32° towards 100°.

0.15 m contorted small-scale cross-laminated sand (Sr).

1.2 m small-scale cross-laminated very fine sand (Sr). In the lower part of the bed there are thin laminae of clay.

0.15 m laminated silt with thin laminae of clay (Fl).

0.9 m massive bluish gray silt. In the lower and upper part of the bed there is faint lamination (Fl--Fm--Fl).

0.45 m yellow, brown and gray laminated silt (Fl).

0.05 m clay with thin laminae of silt (Fl).

0.5 m contorted laminated coarse silt (Fl, Fd).

0.25 m small-scale cross-laminated fine sand (Sr) mainly type-B ripples.

0.7 m small-scale cross-laminated sand and silt (Sr). The silt is accumulated in the trough alternatively as thin laminae. The water transport has been towards the west.

1.2 m laminated fine silt and clay (Fl). In the lower part of the bed the lamination is disturbed.

0.45 m bluish gray or yellowish brown massive fine silt (Fm).

0.9 m contorted laminated silt, clay and silty diamicton (Fl).

0.3 m grayish brown silty clayey diamicton (Dm). The bed has been eroded in the top.

6.5 m trough-bedded cross-laminated sand (St). The bed is a fining upwards sequence. About 4.3 m up in the bed the laminae are dipping 25° towards 143°, 4.8 m up 30° towards 230° and 5.2 m up in the bed 25° towards 174°.

1.1 m stratified silty clay diamicton (Ds). There are many lenses of sand and silt in the bed.

0.9 m contorted laminated silt with thin laminae of red clay (Fl).

1.8 m silty clayey diamicton (Dm). The diamicton is very jointed with many lenses of sand and silt.

0.5 m laminated clayey silt (Fl). In the lower part of the bed there are clasts with vertical long axes, deforming the underlying lamination (dropstones).

1.8 m redbrown sandy diamicton (Dm). In the top of the bed the diamicton is yellowish brown. There are many subvertical light gray or greenish gray thin winding veins of more clayey diamicton.

0.5 m massive sand with organic material (Sm,C).

1.0 m massive sand and silt (loess) with organic content.

Section 10

Section 10 is situated about 900 m west of section 1 and about 50 m west of section 9 (Fig. 26). The section starts at the level of lake Vättern (+88.5 m, Fig. 38).

10 m bluish gray silty clayey diamicton (Dm). The diamicton is jointed. There are some sand lenses in the unit.

10 m alternating beds of horizontally laminated sand (Sh), silt and clay (Fl).

12 m trough-bedded cross-laminated and small-scale cross-laminated sand (St, Sr). There is some gravel in the lower part of the bed.

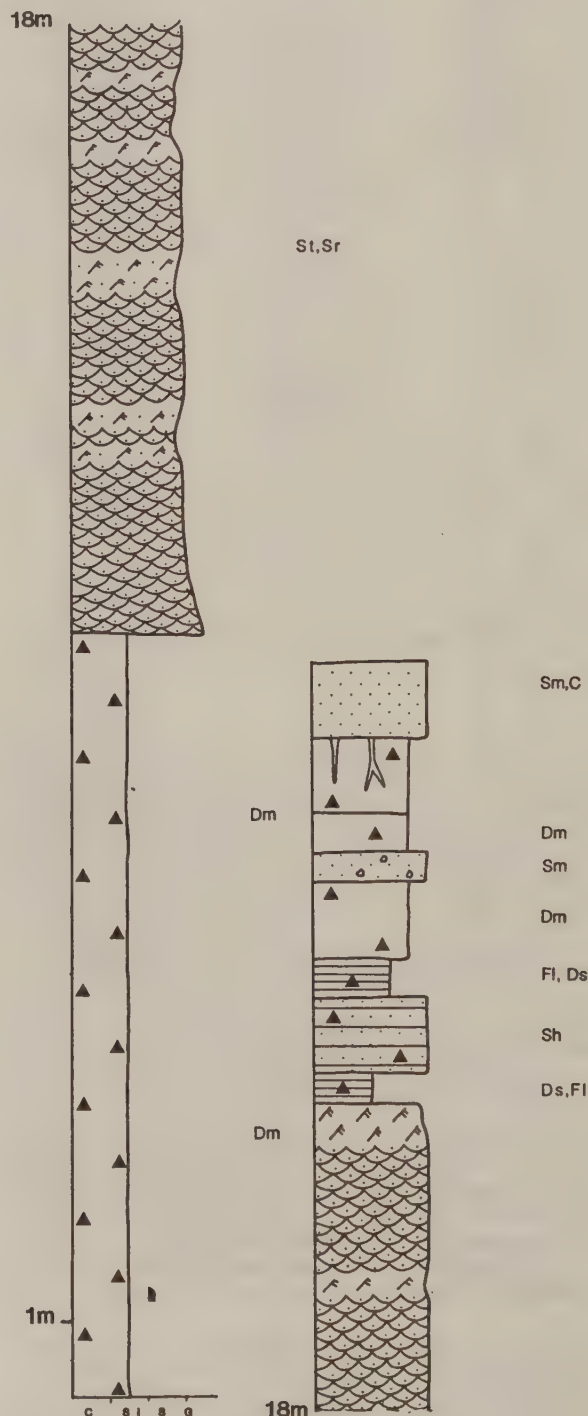


Fig. 38. Log of section 10 at Rosenlund.

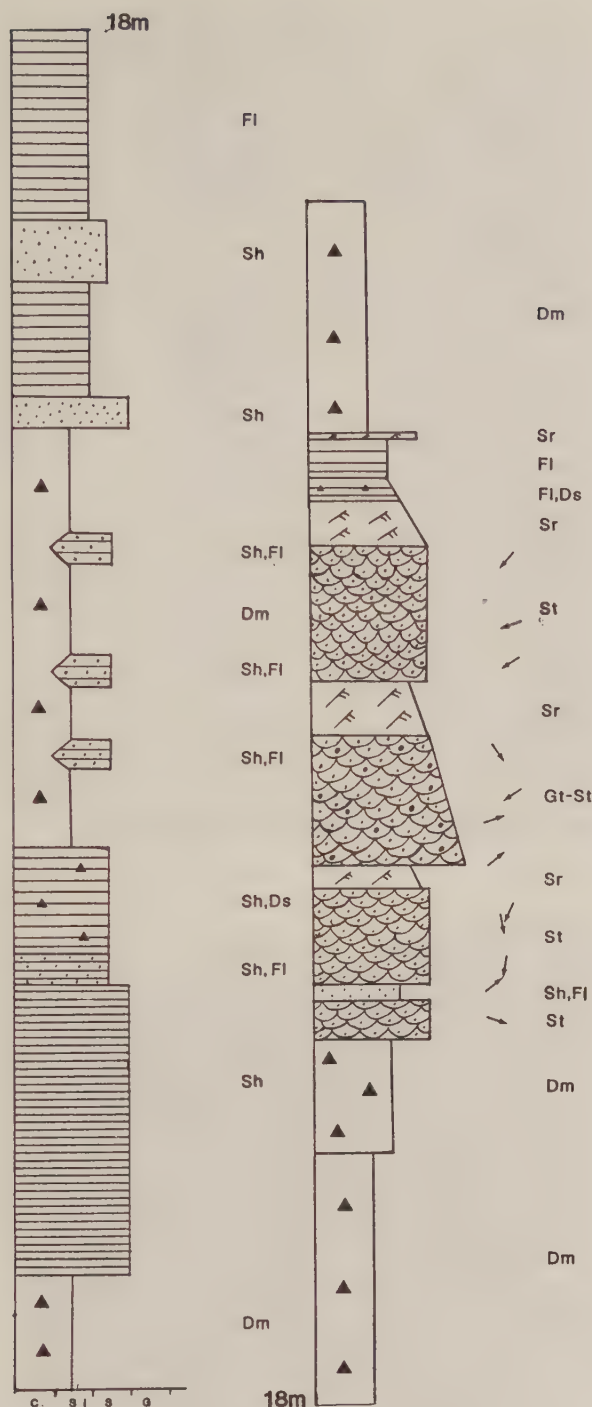


Fig. 39. Log of section 11 at Rosenlund.

0.4 m stratified silty clay diamicton (Ds) with many thin laminae of silt (Fl).

1.0 m horizontally laminated fine sand (Sh). There are cobbles, deforming the underlying lamination in the bed (dropstones).

0.5 m laminated clay, silt and sandy diamicton (Fl, Ds). There are dropstones in the bed.

1.0 m red sandy diamicton with few clasts (Dm).

0.4 m massive poorly sorted sand (Sm). There are pellets of red sandy diamicton in the unit.

0.5 m red sandy diamicton with few clasts

(Dm).

1.0 m redbrown sandy diamicton (Dm). There are thin subvertical winding veins of clayey diamicton in the unit.

1.0 m massive fine sand and silt with organic content (Sm,C). The organic content increases upwards.

Section 11

Section 11 is situated about 100 m west of section 10 (Fig. 26). The section starts at the level of lake Vättern (+88.5 m) and is described from bottom to top (Fig. 39).

1.5 m scree.

1.5 m bluish gray silty clayey diamicton (Dm).

3.8 m contorted horizontally laminated sand (Sh). The sand is reddish.

0.4 m contorted horizontally laminated sand and silt (Sh, Fl). The sediments are unoxidized.

1.5 m alternated horizontally laminated sand and gray silty clayey diamicton (Sh, Ds).

5.5 m bluish gray silty clay diamicton (Dm). There are three lenses with laminated sand and silt (Sh, Fl). The lenses are 0.5, 1.6 and 3.4 m up in the unit. In the uppermost lens the laminae are dipping 36° towards 60°.

0.4 m horizontally laminated sand (Sh). There are thin laminae of silt in the unit. In the lower part of the bed, water escape structures are common.

1.3 m bluish gray laminated silt with thin laminae of clay (Fl).

0.8 m horizontally laminated sand and silt (Sh). The bed is faulted.

2.5 m horizontally laminated silt (Fl).

3.3 m bluish gray silty clayey diamicton (Dm). The bed grades upwards.

1.5 m grayish brown silty diamicton (Dm). The top of the bed is eroded by running water and cobbles and boulders are projecting into overlying sediments.

0.5 m trough-bedded cross-laminated sand (St). The bed is fining upwards. The foreset laminae are dipping 21° towards 108°.

0.2 m rhythmically laminated fine sand and coarse silt (Sh). The laminae are 1-2 mm thick.

1.3 m trough-bedded cross-laminated sand (St). About 0.6 m up in the unit the foreset laminae are dipping 30° towards 60° and in another trough on the same level 12° towards 191°. 0.9 m up in the unit the foreset laminae are dipping 18° towards 177° and 1.1 m up 18° towards 206°.

0.1 m type-A ripples sand (Sr).

0.2 m type-B ripples sand grading into sinusoidal ripples silt (Sr). The sediment was transported towards the south.

1.7 m trough-bedded cross-laminated gravel fining upwards into trough cross-laminated coarse sand (Gt-F St). About 0.1 m up in the unit the laminae are dipping 19° towards 126°, 0.4 m up 14° towards 108°, 0.7 m up 26° towards 233° and 1 m up in the unit 24° towards 151°.

0.3 m type-A ripples medium sand (Sr).

0.3 m type-B ripples medium and fine sand (Sr).

0.06 m sinusoidal ripples silt (Fl).

1.8 m trough-bedded cross-laminated sand (St). About 0.3 m up in the bed, the foreset laminae are dipping 14° towards 234°, about 1.2 m up, 12° towards 252° and 1.5 m up, 6° towards 221°.

0.3 m type-A ripples sand (Sr).
 0.15 type-B ripples fine sand (Sr) grading into horizontally laminated silt and clay (Sr--Fl).
 0.1 m bluish gray horizontally laminated silt (Fl).
 0.2 m yellowish brown horizontally laminated silt (Fl).
 0.1 m horizontally laminated clayey silt and diamicton (Fl, Ds). There are dropstones in the bed.
 0.5 m contorted horizontally laminated silt (Fl).
 0.05 m contorted type-A ripples (Sr).
 3.0 m brownish gray silty clayey diamicton (Dm). The diamicton is jointed.
 6.5 m scree to the top of the section.

Comments

The lenses of laminated sand, silt and silty clayey diamicton in the lower part of the section has an angle far too high to let fine silt be deposited without being deformed. This indicates that the lenses were displaced after deposition.

Section 12

Section 12 is situated about 75 m west of section 11 (Fig. 26). The section starts at the level of lake Vättern (+88.5 m, Fig. 40).

20 m scree.

4.0 m horizontally laminated silt and silty clay diamicton (Fl, Ds). There is successively more laminated silt upwards.

3.3 m trough- and planar-bedded cross-laminated sand (St, Sp). In the lower part of the unit there are two, about 0.2 m thick sequences of type-A ripples sand, grading into sinusoidal ripples silt (Sr). Pebble-size lumps and balls of gray, silty, clayey diamicton and redbrown clay are found in the unit. About 1.3 m up in the unit the foreset laminae are dipping 18° towards 246° , 1.4 m up, 16° towards 148° , 1.8 m up, 20° towards 112° , 1.9 m up, 28° towards 237° and 2 m above the base of the unit, the laminae are dipping 27° towards 263° . The unit is cut by several normal and reverse faults with a displacement of about 0.1 m. There are two main systems of faults. One system with reversed faults with fault-planes dips about 60° to the east and strikes about $5-185^\circ$. The other system consists of normal faults with fault-planes dipping about 65° towards the southwest and striking $126-306^\circ$. Some of the faults are penetrating the overlying beds of sorted sediments, but no fault-plane has been possible to follow through the uppermost diamicton (the Öxnehaga diamicton).

0.9 m horizontally graded laminae of sand and coarse silt (Sg). The unit consists of 15 sequences of medium sands grading into coarse silt.

0.8 m planar-bedded cross-laminated sand (Sp). In the distal part of the laminae type-A ripples have been found, indicating a current in the opposite direction to the dip of the foreset laminae.

4.0 m horizontally laminated and massive coarse silt and fine sand (Sh, Sm). The lamination is very faint and sometimes the stratification is not possible to

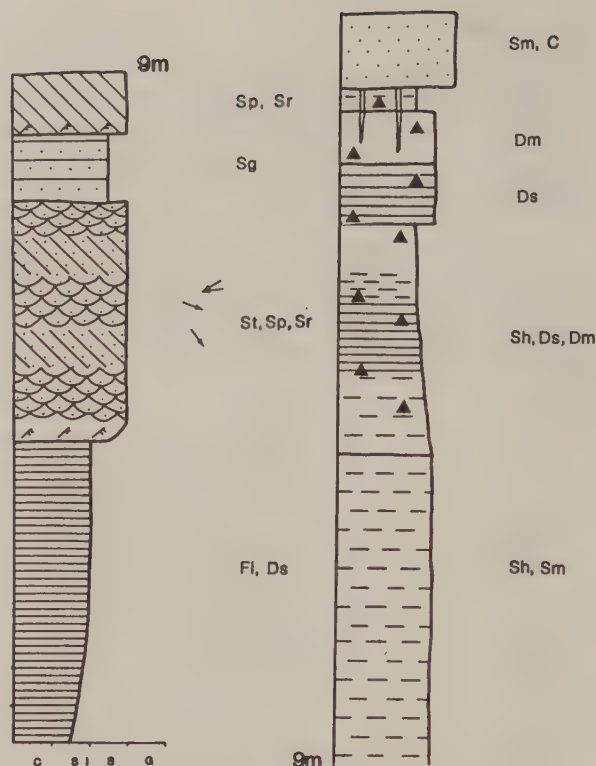


Fig. 40. Log of section 12 at Rosenlund.

distinguish.

3.0 m horizontally laminated coarse silt and fine sand with upwards, successively higher frequency of laminae of silty diamicton (Sh--Ds--Dm). In the upper part of the bed the diamicton is massive with only a few thin silt laminae. The diamicton is brownish gray and jointed in one subvertical and one sub-horizontal system. The unit grades into the overlying unit.

0.8 m redbrown faintly laminated sandy silty diamicton (Ds).

0.7 m red sandy silty diamicton (Dm). There are lenses of silt in the upper part of the bed. There are also subvertical winding veins of light gray clay. The veins are rounded and appear to be clustered in a zone in the middle of the bed. A fabric analysis was made in the middle of the bed (Fig. 40).

0.3 m yellowish brown faintly laminated silty diamicton (Ds). There are thin subvertical winding veins of light gray clay in the unit.

1.0 m massive sand and silt (loess) with organic content (Sm, C).

Comments

In the red, sandy, silty diamicton (Öxnehaga diamicton) about 2 m below the ground, two wedges have been found. It is possible to follow them about 7 m down into the underlying sediments. The wedges are filled with laminated sandy, silty diamicton, silt and clay. 2-5 sets of rhythmically laminated silt and clay have also been found (Fig. 41). The laminae stand vertical and show few disturbances. About 7 m down the laminated silt and clay in the wedges continue in a horizontal lamina in the faintly laminated or massive fine sand. From the horizontal clay

laminae, a wedge, consisting of 4 rhythmically laminated sets of clay and silt, was possible to follow at least 1 m further down. The horizontal and the vertical clay laminae are deposited at the same time. The horizontal part of the wedge was possible to trace into the eastern wedge. The easternmost wedge dips 82° towards the southwest and strikes $58-238^\circ$. Laminated silt and clay can not be deposited in a vertical position, this indicates that the wedges were opened successively. No disturbances are found in the surrounding sediments, indicating deformation during or after the sedimentation. The wedges end in the middle of the Öxnehaga diamicton, which was deposited from a glacier in the Vättern basin in a subaquatic or subglacial environment. This together with the statements above indicate that the wedges are not fossil ice-wedges. They might be extension fractures formed by horizontal stress, induced by a grounding glacier depositing material. Another possibility is that the fractures were opened due to release of ice support in the vicinity. Buried ice melts very slowly and it is possible that it melted at the same time as the Öxnehaga diamicton was deposited. The successive opening of the fractures is not in accordance with what is known about the release from melting buried ice, which supposedly is intermittent. The most simple solution is a horizontal glaciotectionic stress from a floating glacier or ice shelf, occasionally grounding in the area.



Fig. 41. The lower part of the long wedge in section 12.

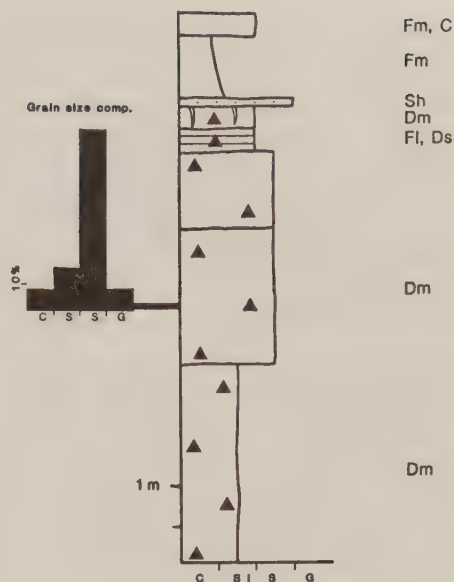


Fig. 42. Log of section 13 at Rosenlund.

Section 13

Section 13 is situated about 25 m northeast of the camp site at Rosenlunds bankar (Fig. 26). The investigated wall strikes $116^\circ-296^\circ$. The stratigraphy is described from the level of lake Vättern (+88.5 m, Fig. 42).

30 m scree.

2.6 m bluish gray silty clayey diamicton (Dm). It is very compact and jointed, with iron- and manganese oxides in the fractures. Three joint systems are recognized. Two of the systems are perpendicular, and the other dips about 45° to the others. The perpendicular systems are subvertical and subhorizontal. Some of the subvertical fractures are possible to follow up into the overlying unit.

Two fabric analyses were made in the upper part of the bed (Fig. 42). In the upper part of the bed there are many lenses of red sandy diamicton (of the same kind as the overlying diamicton). The contact to overlying diamicton is interbedded.

1.8 m folded gray sandy silty diamicton and red sandy diamicton (Dm). Lenses of sand and silt are common. The sediment lenses are disturbed, (indicating a pressure from the northwest). The red sandy diamicton is quite soft and lies in contact with the underlying diamicton in most of the section. Most of the subvertical joints and the joints with an angle of 45° to the horizontal, continue up into this bed. Most of the joints die out in the upper part of the bed. Some of the fractures in the 45° system are filled with sand, gravel and balls of surrounding diamicton. These fractures are up to 0.04 m wide. One of the sandfilled joints displaces fractures in the subvertical system. The sandfilled joints dip and strike 47° towards the south and $101^\circ-281^\circ$, 41° towards the southeast and $46^\circ-226^\circ$, 34° towards the south and $91^\circ-271^\circ$ and 80° towards the south and $75-225^\circ$. There are two striated boulders in the bed with striae in $138-318^\circ$, $136-316^\circ$ resp. A fabric analysis is made about 0.2 m up in the bed (Fig. 42).

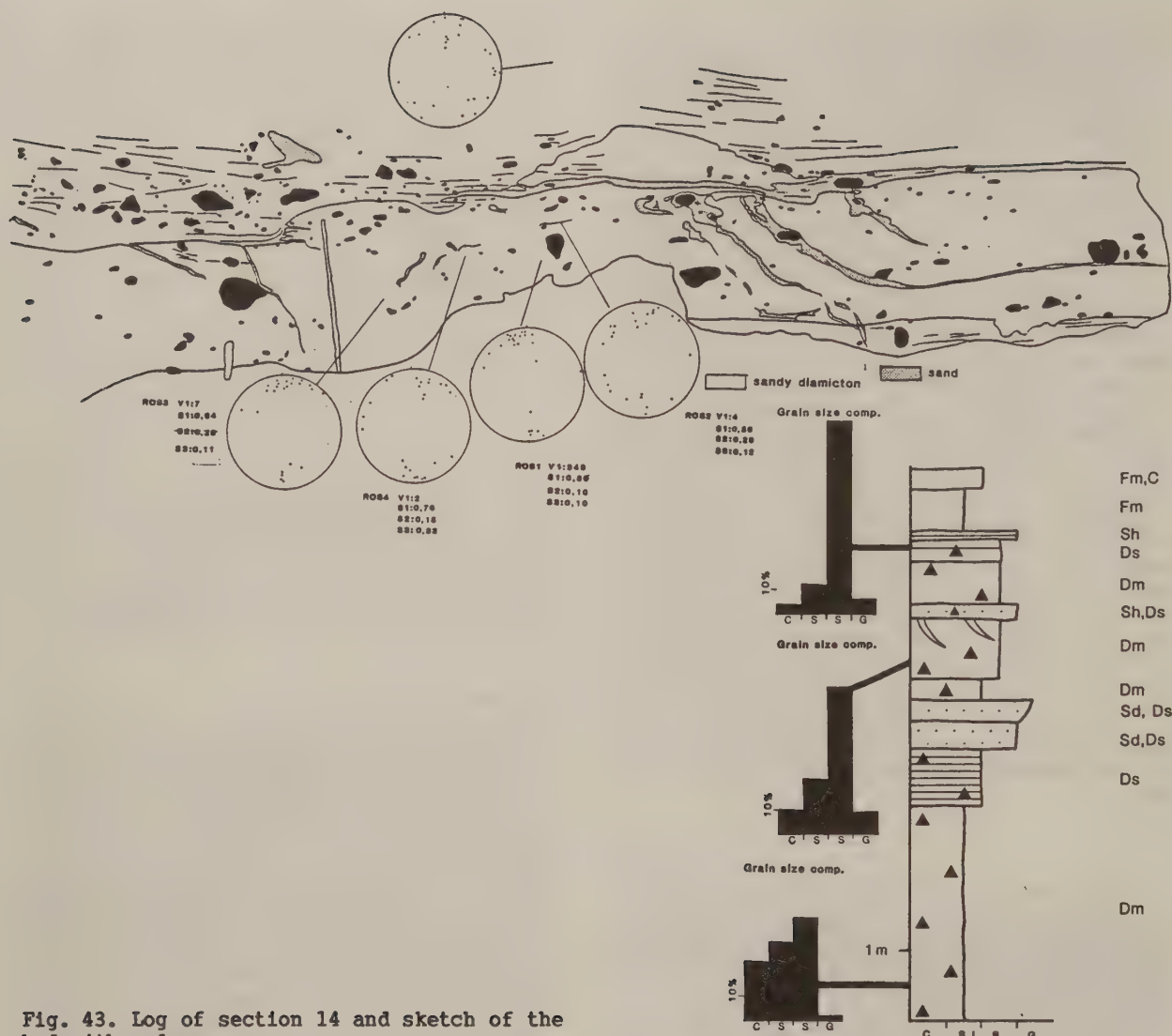


Fig. 43. Log of section 14 and sketch of the bed with wedges.

1.0 m dark grayish red sandy silty diamicton (Dm). It is very heterogeneous with many thin winding laminae of fine sand. The diamicton is jointed, with iron and manganese oxides in the fractures.

0.3 m light brown silt with thin laminae of diamicton (F1, Ds). The lower contact is sharp but undulating. The bed is grading into overlying diamicton.

0.3 m redbrown sandy silty diamicton (Dm), with thin subvertical veins of more clayey diamicton.

0.1 m horizontally laminated sand (Sh).

0.8 m massive clay (Fm). The texture becomes finer upwards.

0.3 m massive clay with organic material (Fm,C).

Section 14

The section is situated about 15 m southwest of section 13 (Fig. 26). The wall strikes 30-210°. The stratigraphy is described from the level of lake Vättern (+88,5 m, Figs. 43 and 44).

30 m scree.

3.0 m bluish gray silty clay diamicton (Dm). It is jointed with iron and manganese oxides

in the fractures. An analysis of the jointings is presented below.

0.8 m olive green stratified silty diamicton (Ds). There are lenses of fine sand within the lenses of redbrown sandy diamicton in the unit. In the silty diamicton there are thin laminae of silt. The bed is jointed in a subvertical and a subhorizontal system (see further below). Bigger clasts appear to be grouped around the lenses of sandy diamicton.

0.4 m contorted laminated sand with laminae of red sandy diamicton (Sd,Ds). The diamicton laminae are wedging out towards the south.

0.3 m contorted laminated gravely sand, with thin laminae of red sandy diamicton (Sd,Ds). In the lower part of the bed there are some thin laminae of gray silty diamicton (Ds).

0.3 m brownish, gray silty diamicton (Dm). The unit is jointed and tapers towards the south.

0.6-1.0 m redbrown sandy silty diamicton (Dm). The bed becomes thicker towards the south. There is a relatively high content of usually well rounded clasts in the bed. The diamicton displays small scale jointing (fissility). In the bed there are many wedge-like structures (Figs. 43,44 and 45) mostly filled with laminated sand. Gravel, lumps of redbrown sandy diamicton and laminated silt

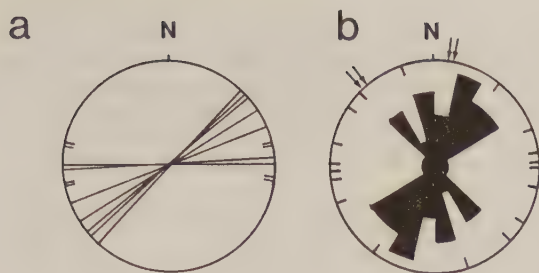


Fig. 44 a) the strike of sand filled wedges- and the strike of foldaxis of overturned fractures ——— in sections 13 and 14.
b) the strike of subvertical joints strike of sediment filled fractures and striae on clasts in section 13 and 14 \.

have also been observed. The upper ends of the wedges start in a thin bed of laminated sand with a thin diamicton lamina. Most of the wedges can be followed about 0,8 m down into the bed where they bend southwards, become horizontal (Figs. 43 and 44) and die out. It is possible to follow one of the wedges through the bed and down into the upper part of the underlying unit. One of the wedges is deformed and another is folded (Fig 43 and 44).

One of the wedges cuts over a striated cobble, the striae has a direction of 10-190°. There are imprints from the cobble on both walls of the wedge. The wedges are possible to follow at least 0,5 m into the wall of excavation. The dips and strikes of the wedges are shown in Fig. 45. Four fabric analyses were made in the bed (Fig. 43).

0,2 m horizontally laminated sand with some

thin laminae of red sandy diamicton (Sh,Ds). 0,6 m redbrown sandy silty diamicton (Dm). There are many lenses and laminae of fine sand in the unit. In the southern part of the excavation, there is a network of sand laminae splitting the diamicton into cubes. Most of the laminae run at an angle of about 45° to the horizontal. Some of the sand laminae are possible to follow from overlying laminated sand to underlying laminated sand. In another part of the bed there is a small wedge, looking like those in the underlying bed. Folded sand laminae are also found in the unit.

0,3 m yellowish gray stratified sandy silty diamicton (Ds). It is homogeneous and has sharp upper and lower boundaries. A small clast in the sole of the bed projects down into underlying material. South of the clast a small mound has been pushed up, indicating a shear stress between the beds.

0,1 m brownish gray horizontally laminated silt and fine sand (Sh). It contains many aggregates due to secondary processes.

0,6 m poorly sorted silt and clay (Fm).

0,3 m massive silt and clay with organic material (Fm,C).

Analyses of section 13 and 14.

The diamicton in the sections are jointed from approximately 2 m below the ground and downwards. Two almost perpendicular systems dominate. One is subvertical and the other is subhorizontal. The fractures are 1-5 mm wide, with iron and manganese oxides in the fractures. The joints are 0,1-0,2 m apart, with a diminishing interspacing downwards. The subhorizontal system is more irregularly spaced than the subvertical joints. The strikes of 30 subvertical joints are shown in



Fig. 45. The sand filled wedges in section 14 at Rosenlund.

Fig. 45. A third set of joints is frequent in the sections. The joints dip about 45° to the horizontal. The fractures are 1-5 cm wide, usually filled with sand, but sometimes filled with clay, silt, diamicton or even gravel. The dip and strikes of sandfilled joints are shown in Fig. 45. One of the sandfilled joints has displaced a joint in the subvertical system, indicating that the sandfilled system is younger than the subvertical system. Some of the sandfilled fractures in the Rosenlund diamicton become successively steeper and more narrow upwards. In the lower part of the Öxnehaga diamicton these joints are almost vertical and about 2 m up, some of the joints decrease while others are overturned (towards the south) becoming almost horizontal. The foldplane of the joints always dips towards the south. The foldaxes of some of the overturned joints are shown in Fig. 45.

Discussion of section 13 and 14.

The lowermost silty clayey diamicton is part of the Rosenlund diamicton. The bed is jointed (see above). The fractures are possible to follow up into the overlying Öxnehaga diamicton, where most of them either disappear or are overturned. This indicates that the joints were created when one of the overlying units was deposited, most likely just above the level where the joints are overturned. Two fabric analyses were made close to the contact of the overlying Öxnehaga diamicton (Fig. 42). Both display almost random orientation of clasts long axes, with a median dip of about $22-26^{\circ}$. Most clasts are disk-shaped and often striated. The random fabric indicates that the clasts might have been dropped from icebergs, a floating glacier or an iceshelf. A higher imbrication might be expected, but ice-dropped sediments with low imbrication have been reported (Kurtz and Anderson 1979).

The random fabric indicates that the Rosenlund diamicton was not deposited by a subglacial process, which usually produces a good preferred orientation. Other possibilities are debris flow deposits, debris being dropped from icebergs or a floating glacier or ice-shelf. In the shear zone of debris flows, clasts are parallel to the direction of the flow (Enos 1977, Carter 1975) and in the rigid plug (Lawson 1979) the particle orientation is not altered during the transport. Fine grained particles are suspended from the surface of the debris flow. When the debris flow has settled the cloud of fines started to fall out and a thin lamina of fines is deposited (Hampton 1975). The random fabric and the lack of sedimentary structures indicate that the Rosenlund diamicton might not have been deposited by debris flows.

This lack of sedimentary structures is not expected from dropped material, except if the distance between the sole of the glacier and the bottom is very small and the concentration of sediment is high. The most likely depositional process is material being melted out from the sole of a floating glacier in very shallow water. The distance between the sole of the glacier and the bottom is probably less than 1 m (May 1977, Gravenor et al 1984). According to Gravenor et al this kind of undermelt diamicton seldom displays

preferred clast orientation.

In section 14 the Rosenlund diamicton grades into a stratified olivegreen silty diamicton, with many lenses of sorted sediments and coarser diamicton. This bed is likely to have been deposited by a series of subaqueous debris flows.

The overlying laminated sand with lenses of red sandy diamicton appears to have many characteristics of subaquatic sediment gravity flows. Superimposed there is a thin bed of silty diamicton, which is wedging out towards the south. The bed looks like the underlying olive green diamicton and was probably also deposited by a debris flow process. In the overlying redbrown sandy silty diamicton there are wedges filled with laminated sand, gravel or pieces of surrounding diamicton. The upper parts of the sand wedges were deformed by a drag force coming from a northern sector. All the wedges dip towards the south and strike approximately east-west (Fig. 45). In the four fabric analyses the clast long axes display a preferred orientation around 0° of clast long axes (Fig. 43). Two cobbles with their long axes in $10-190^{\circ}$ were striated in the same direction (Fig. 45).

The sandfilled joints in section 13 diminish or are overturned at the same level as the unit with the sand filled wedges in section 14. These deformation structures indicate high shear stress in the upper part of the diamicton bed with the wedges.

The shearing was most probably caused by the drag forces from a grounding glacier or iceshelf. It has not been possible to determine whether the whole unit was subglacially deposited or the fabric is a product of clast reorientation of earlier deposited sediments due to high stress induced by a grounding glacier (Boulton et al 1974).

The overlying sand with diamicton laminae is a sediment gravity flow deposit. The superimposed bed of sandy silty diamicton is also a debris flow deposit. The brecciated part of the bed might be an extended part of a rigid plug in a debris flow (Lawson 1979, Carter 1975). Another possibility is that the bed was deposited by a subaqueous debris flow and afterwards sheared when a floating glacier temporarily grounded.

The overlying stratified diamicton was deposited in a subaqueous environment, probably by debris flows, but material dropped from icebergs and/or a floating glacier could be a large part of the material in the bed.

The poorly sorted clay is a mixture of fine material fallen out of suspension and material being dropped from floating icebergs or a floating glacier. The small clast content could be due to a very high sedimentation rate of fines diluting the dropped clasts. This type of sedimentation is expected close to the glacier margin or under a floating glacier (Boulton and Deynoux 1981). The same kind of bed is also expected in a very distal position to the ice front where the icebergs or iceshelf have lost most of their debris (Drewry and Cooper 1981, Orheim and Elverhøi 1981).

Section 15

Section 15 is situated about 150 m southwest of section 14. The section starts at the

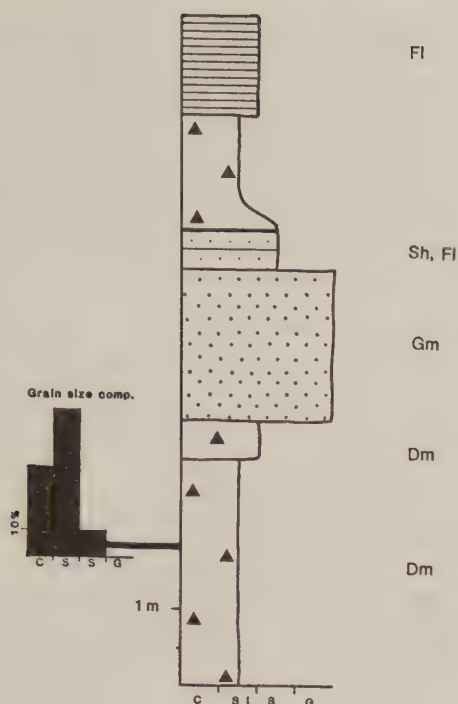


Fig. 46. Log of section 15 at Rosenlund.

level of lake Vättern (+88,5 m, Fig. 46).
20 m scree.

3,0 m bluish gray silty clayey diamicton (Dm). It is compact and jointed.

0,5 m brownish gray clayey silty diamicton (Dm). It is homogeneous and very compact.

2,0 m massive pebble gravel (Gm).

0,5 m horizontally laminated sand and silt (Sh, Fl).

1,5 m gray silty clayey diamicton (Dm). It is compact and jointed. There are very few clasts in the bed. In the contact zone to the underlying bed there are some lenses of gravelly sand in a silty matrix. About 1 m east of the section the bed is eroded and replaced by a gravelly sand unit.

1,3 m laminated silt with thin laminae of sand (Fl). The laminae in the bed are dipping 18° towards 216° , (which indicates a secondary tilting of the unit). In the unit there is a thrust fault dipping 38° towards the southeast and striking $41-221^\circ$.

0,4 m gray sandy silty diamicton (Dm). It is homogeneous with well rounded clasts.

1,0 m mainly grayish red clay (Fl). There is no visible lamination in the unit.

0,3 m yellowish stratified sandy diamicton (Ds).

0,15 m horizontally laminated fine sand (Sh).

0,3 m yellowish gray stratified sandy diamicton (Ds).

0,5 m massive gravelly sand with organic material (Sm).

Section 16

About 100 m southwest of section 14 and about 50 m northeast of section 15, samples of the Rosenlund diamicton were collected at different levels. The texture and the rock fragment composition are shown in Fig. 47.

Sample 1 was collected 7 m above the level of

lake Vättern.

Sample 2 was collected 15 m above the level of lake Vättern.

Sample 3 was collected 21 m above the level of lake Vättern.

Sample 4 was collected 27 m above the level of lake Vättern.

The texture and the rock fragment composition are presented in Fig. 47.

7:1:3 Discussion

The general picture of the Rosenlund bankar is shown in Figs. 27 and 28. The eastern part of the bluff is dominated by sorted sediments, the western part is dominated by silty clayey diamicton.

Rosenlund diamicton

The silty clayey diamicton in the lower part of the bed is called Rosenlund diamicton.

Texture: The grain size composition of the Rosenlund diamicton is homogeneous throughout the whole cliff. The grain size composition is very characteristic with an extremely high silt content (40-60%). The clasts are usually rounded or well rounded and disk-shaped gravel. The clasts, especially the shale, are often striated.

Rock fragment composition: The rock fragment composition is very homogeneous throughout the bed. The diamicton is composed of about 90% sandstone and shale from the Visingsö Group of Rocks and about 10% crystalline rocks (Fig. 47).

Fabric: Two fabric analyses were made in the Rosenlund diamicton, both in the upper part of the bed in section 13 (Fig. 42). They show an almost random orientation of clast long axes.

Joints: The Rosenlund diamicton is jointed throughout the whole bluff. Usually there are two almost perpendicular sets of joints. One system is subvertical and the other is subhorizontal. A joint analysis was made in sections 13 and 14 (Fig. 45). The 30 measured subvertical joints show a tight cluster around $0-180^\circ$. The joint fractures are usually 1-5 mm wide and 10-20 cm apart. Iron and manganese oxides are precipitated in the fractures.

Another set of joints is also present in these sections. Here the joints dip at about 45° to the horizontal. The fractures are 1-5 cm wide and filled with gravel, sand, silt, clay, diamicton or lumps of diamicton in a sandy matrix. The joints are usually very extensive. No signs of movement along the fractures are noted, except in section 13

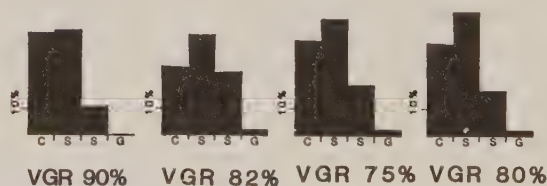


Fig. 47. Grain size composition and rock fragment composition in section 16 at Rosenlund.

where a subvertical jointfracture has been displaced.

It has been suggested in the literature (Boulton and Paul 1976, Grisak et al 1976) that jointing or fracture in till develops from dessication (Boulton and Paul 1976), unloading during iceretreat rebounding (Boulton and Dent 1974), removal of lateral stresses, (Boulton, Dent and Morris 1974), postglacial freeze-thaw mechanisms, subglacial shear (Boulton 1970a) and the development of conjugate tensile stresses in the subglacial environment.

The displacement of sandpods in the sub-horizontal system indicates shearstresses. There are no signs of displacement along the subvertical joints. The regular spacing and direction of the joints indicate that they have been developed by either dessication or rebound, due to unloading during the ice retreat.

Surface morphology and internal structures: Erosion by massmovement or fluvial erosion and plucking (Arnborg 1957) have eroded deep trenches (sometimes more than 25 m deep) in the surface of the Rosenlund diamict. According to Arnborg (1957) fluvial erosion of a jointed sediment can be very fast and extensive. There is no erosional lag in the bottom of the trenches. This indicates that the diamict was eroded in aggregates (lump by lump) and/or that the eroding stream was competent to carry all eroded particles. This aggregate erosion indicates that the diamict is consolidated and probably also jointed before the erosion started (Arnborg 1957).

There are very few structures in the homogeneous Rosenlund diamict. Only tilted and deformed lenses of sand and silt have been observed. Faults, folds and contorted lamination in overlying sediments indicate syn- or postdepositional movements, which could be due to subsidence caused by density differences of the units, collapses due to melting of buried or supporting ice or glaciotectionic pressures. It is likely that the sand and gravel had a higher density than the Rosenlund diamict. The fact that the column of sand and gravel is higher over the trench bottom than over the higher parts of the Rosenlund diamict could lead to extensive subsidence and sharpening of the trench profile. This might lead to deformation of the sediments in the trenches if the diamict was not overconsolidated. There is no extensive faulting in Rosenlunds bankar which is expected if buried ice was present in Rosenlunds bankar during or after the time when the sediments were deposited. The sediment lenses in the Rosenlund diamict do not show any extensive glaciotectionic deformation, which would be the case if the Rosenlund diamict is a deformed sediment. The tilting and slight deformation of the sediment lenses indicate subglacial shearing. **Interpretation:** The high silt and clay content indicates that the Rosenlund diamict might be a reworked glaciolacustrine sediment (Svantesson 1985).

The Rosenlund diamict could have been consolidated in two ways. The diamict was either deposited or deformed under a moving glacier or the diamict was dried out. The Rosenlund diamict could have been dried out only if the waterlevel was lower than today. This is possible only if a col was open either towards the east, over the Östergötland plain, or towards the north,

north of mount Billingen. This is possible according to Björck and Digerfeldt (1984) but there are no other indications of a low waterlevel before the Sanna beds and the Öxnehaga diamict were deposited.

The thickness of the bed, the homogeneity, the tilted but not deformed lenses of sorted sediments and the lack of preferred orientation indicate that the Rosenlund diamict was not deposited by a lodgement process (Boulton and Deynoux 1982, Gravenor et al 1984).

A glaciolacustrine sediment is supposedly laminated (Ashley 1975, May 1977, Evenson et al 1977, Gibbard 1980). It is unlikely that a subglacial deformation of thick laminated glaciolacustrine sediments would form a homogeneous diamict, like the Rosenlund diamict. There are lenses of horizontally laminated sand, silt and clay in the Rosenlund diamict. The lenses are tilted but not deformed to any higher extent. This indicates that the Rosenlund diamict is not a glaciotectionically deformed glaciolacustrine sediment. The most plausible explanation is that the Rosenlund diamict was deposited under a floating glacier (Powell 1981) or under an iceshelf near the grounding line (Domack 1981, 1983, Drewry and Cooper 1981, Orheim and Elverhøi 1981) as an undermelt diamict (Gravenor et al 1984, May 1977, Eyles and Eyles 1983). The overconsolidation, deformation and shearstructures are formed at intervals when the glacier grounded.

Sanna beds

The sorted sediment superimposed on the Rosenlund diamict is called the Sanna beds. The Sanna beds exceed 35 m in thickness and are more than 1 km wide. The north-south extension of the bed is not known, but is likely to have extended at least 2 km to the north of Rosenlunds bankar and there are indications (drilling logs) of an extension of at least 1 km south of the section.

Texture and structures: The Sanna beds consist mainly of cross-laminated and small-scale cross-laminated sand, but horizontally laminated and massive beds of sand, silt, clay and diamict are commonly found. Beds of cross and horizontally laminated gravel also occur.

Rock fragment composition : Only one sample has been analyzed. It contains 79% of Visingsö Group of Rocks and 21% crystalline rocks.

Deformation and displacement: In the lower and upper part of the Sanna beds the lamination is sometimes contorted, folded or faulted. The observed faults are always of a minor extension with displacements in the range of a few centimeters. Small folds have also been observed in the contact zone to overlying sediments.

Paleocurrent: Paleocurrent analyses have been made in most sections and in some areas in between (Fig. 21). All paleocurrent measurements indicate a watertransport towards the south (Fig. 21).

The dip of undisturbed beds and laminae of fine silt and clay have been measured in order to find out if these sediments were tilted after sedimentation. Fine silt and clay in soaked condition start to creep in a slope, exceeding 5° (Prior and Coleman 1980). The units show no deformation of creeping

suggesting the units are horizontally deposited. Most measured beds and laminae show little or no postdepositional displacement.

Interpretation: The Sanna beds in Rosenlunds bankar could theoretically have been deposited in three different environments: 1) subaerial, 2) subglacial or 3) subaqueous.

1) Subaerial environment: The Sanna beds were deposited by water flowing to the south. The cols in the southern part of the Vättern basin are situated at about +220 m. This means that if the Sanna beds were subaerially deposited, these sediments and the Rosenlund diamicton must have been deposited on top of more than 140 m of ice, which later melted without disturbing the overlying sediments. Most laminae and beds dip towards the south. This is not expected from a sediment column let down on the steep (Fig. 2) north facing basement slope (Fig. 2).

2) Subglacial environment: The extensive erosion of underlying Rosenlund diamicton is probably in a subglacial environment. The very wide bed of sorted sediments (more than 1 km), the textures and structures, the many beds of massive or horizontally laminated silt, clay and diamicton, indicate a more calm place of deposition than inside a subglacial tunnel.

Subaqueatic environment: The extensive beds of gravel and the large slabs of silty clayey diamicton in the sorted sediments indicate that the deposition could not have been far from the entrance of a glaciofluvial tunnel. The beds of cohesive sediments, the laminated diamicton and the dropstones, indicate that the Sanna beds were deposited in a glaciolacustrine environment near the glacier front or under a floating glacier.

The extensive beds of gravel and the slabs of silty clayey diamicton in the sorted sediment imply that deposition took place not far from a glaciofluvial tunnel, if the slabs were transported with the glacial stream. The slabs could also have been formed by undercutting of the trenches in a subaqueatic position.

Interpretation: The Sanna beds were deposited in a subaqueous environment in a more than 100 m deep lake. It has not been possible to find out whether there was a floating glacier, an iceshelf or if a calving ice-front was close to the area when the Sanna beds were deposited.

Öxnehaga diamicton

The Öxnehaga diamicton is nearly always red or reddish gray. It is usually about 6 m thick. In the eastern and highest parts of Rosenlunds bankar it wedges out.

Texture: The Öxnehaga diamicton has a heterogeneous grain size composition. It is mainly sandy, but silty and clayey varieties occur. The texture seems to reflect the underlying sediments.

In the diamicton beds, as well as in the interbedded laminated sorted sediments, there are pellets of diamicton. According to Oven-shine (1970) diamicton pellets are diagnostic of deposition from overturning icebergs.

Rock fragment composition. The rock fragment composition in the Öxnehaga diamicton contains 65-88% sandstone and shale from the Visings Group of Rocks and 12-35% crystalline

rocks.

Structures: The Öxnehaga diamicton often consists of many beds of massive or stratified diamicton separated by sand, silt or clay. The contact to underlying sediment is usually graded or interbedded. In some sections sorted sediments from below have been incorporated into the Öxnehaga diamicton. Lenses of sand, silt and clay often display extensive faulting and folding. In section 14 there are structures looking like tillwedges (Mrner 1972, Dionne and Shilts 1974, Humlum 1978). The wedges are not filled with till but with sorted sediments, usually sand.

Fabric: Seven fabric analyses were made in the Öxnehaga diamicton. Four of them were made in the bed with the wedge like structures. All these analyses display good preferred clast orientation (Fig. 43). The other analyses have been made in other levels and show almost random clast orientation.

Joints: The lower part of the Öxnehaga diamicton is at some places jointed, in the same way as the Rosenlund diamicton. (See section 13 and 14). The sandfilled joints in the Sanna beds and Rosenlund diamicton are possible to follow up in the Öxnehaga diamicton. About 2 m up in the bed the joints are either overturned or have diminished out. In section 13 and 14 the overturned joints are found on the same level as the bed containing the wedges and the good preferred clast orientation.

Interpretations: The abundant laminae of fine silt and clay indicate that the lower part of the Öxnehaga diamicton was deposited in a subaqueous environment.

Miall (1983) has described how sediment from below, underlying sediments, were incorporated into subaqueous sediment gravity flows. Gradational and interbedded contacts are expected in a proximal glaciolacustrine environment. (Eyles & Eyles 1983).

In the middle of the Öxnehaga diamicton there is a bed with wedges filled with laminated sediments. The fractures have a unidirectional strike, approximately perpendicular to the fabric in the bed and striae on clasts in the unit. The structures are interpreted as extension joints which might have been formed either by removal of lateral support (melting of buried ice) or by a drag force working on the top of the bed. There are no fault or collapse structures in the bed, indicating melting out of buried ice.

There is a good preferred clast orientation in the bed indicating that shear stress worked on the bed. It is on this level of the Öxnehaga diamicton that the sandfilled joints either fade out or are overturned. This indicates that the dragforce, that formed the fractures, worked on the surface of this bed. The described properties indicate that the bed was deformed and/or deposited subglacially. The upper part of the Öxnehaga diamicton was deposited in the same way as the lower part of the unit.

Depositional model: The lower part of the Öxnehaga diamicton was deposited in a subaqueous environment by sediment gravity flows, rain-out of sediments from icebergs or a floating glacier (Eyles & Eyles 1983). The middle part of the bed seems to have been deposited in a subglacial environment. As the glacier receded, the upper part of the Öxnehaga diamicton was deposited in the same way as the lower part of the bed.

Ekhagen clay

The Ekhagen clay superimposes the Öxnehaga diamicton. The contact is usually graded. The Ekhagen clay is usually massive and poorly sorted, but in the western part of the cliff it is rhythmically laminated. The unit is deposited in a distal glaciolacustrine environment.

7:2 The coastal cliff at Vilhelmsro.

Along the western shore of lake Vättern there is a two km long, 10-15 m high coastal cliff. Most of the cliff is covered by vegetation. About 100 m southwest of the chapel at Vilhelmsro hospital there is a 100 m long and 15 m high bluff, almost free of vegetation. The site is called Vilhelmsro (Fig. 25). Fig. 48 shows the position of the 17 sections described in this site.

7:2:1 Introduction

South of Vilhelmsro chapel (Fig. 43) there is an approximately 100 m long and 10-15 m high cliff, sections 3-16 are from this part of the site. Only in the middle of the cliff it has been possible, due to thick talus, to get continuous sections from the lake level to the top of the cliff.

In these sections it is possible to see the Kaptensbo beds, the Rosenlund diamicton and the Öxnehaga diamicton.

The Kaptensbo beds consist of horizontally laminated sand, silt, clay and diamicton. The lamination has occasionally been disturbed by pebbles and cobbles (dropstones).

The lamination is often contorted and folded due to tectonic pressures and waterscape structures.

Conformable over the Kaptensbo beds lies the **Rosenlund diamicton**. The diamicton is jointed with iron and manganese oxides precipitated in the fractures. The texture is very homogeneous with a high silt and clay content.

The rock fragment composition of the Rosenlund diamicton varies between 72-87% with a mean of 79% sandstone and shale from the Visingsö Group of Rocks and 21% crystalline rocks. This is about 10% lower than the content of the Visingsö Group of Rocks from the Rosenlund diamicton in Rosenlunds bankar and from the sites on the eastern side of lake

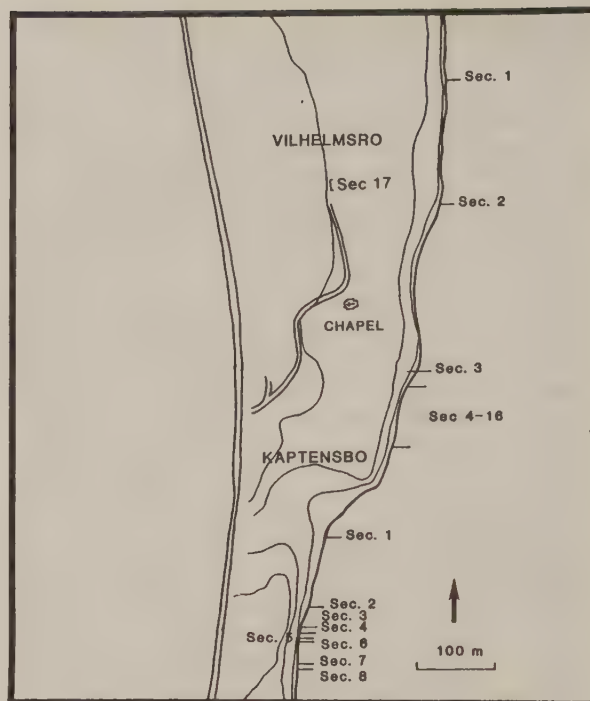


Fig. 48. Topographic map of the Vilhelmsro and Kaptensbo area.

Vättern.

In the northern part of the cliff, the **Öxnehaga diamicton** lies concordant on top of the Rosenlund diamicton. The Öxnehaga diamicton is sandy or silty with a heterogeneous texture. There is often a thin bed of laminated sand between the two diamicton units.

The lower part of the Öxnehaga diamicton shows faint lamination, with many lenses and laminae of sorted sediments. The rock fragment composition of the Öxnehaga diamicton contains between 62-71% with a mean of 65% Visingsö Group of Rocks and about 35% crystalline rocks.

The sections at Vilhelmsro were examined in 1980 and in 1981. In the autumn of 1984 a new, broad section was formed by the wave action in the lake Vättern. This new section covers most of section 5-9 (see below) described earlier. In this new section, a big



Fig. 49. Sketch of the fold at Vilhelmsro.

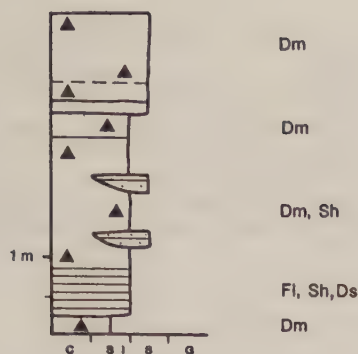


Fig. 50. Log of section 1 at Vilhelmsro.

fold was found (Fig. 49), showing that parts of the stratigraphy in section 5-9 and probably also parts of section 10-16 are repeated.

7:2:2 Sections

Section 1

Section 1 is situated about 200 m NE of the chapel at Vilhelmsro (Fig. 43). The section starts at the level of lake Vättern (+88,5 m, Fig. 50).

6,5 m scree.

0,25 m bluish gray silty clayey diamicton (Dm). It is highly jointed, with iron and manganese oxides precipitated in the fractures.

0,60 m Contorted laminated clay, silt, sand and diamicton. (Fl, Sh).

1,70 m jointed grayish brown silty clayey diamicton (Ds). In the middle of the bed there is a 5 cm wide fracture filled with sand. There are many contorted lenses of coarse silt and sand in the whole bed.

0,30 m brownish gray silty diamicton (Dm).

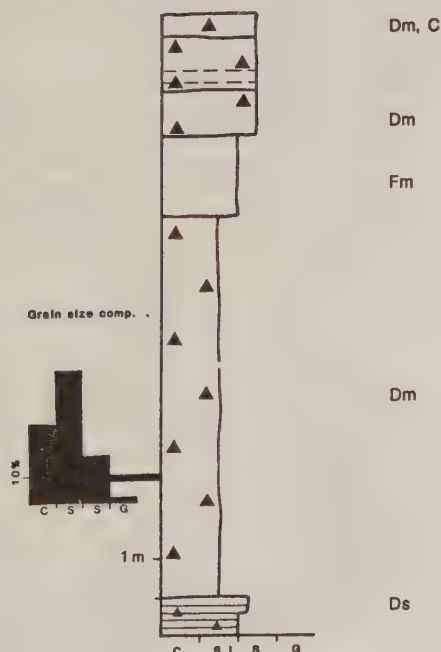


Fig. 51. Log of section 2 at Vilhelmsro.

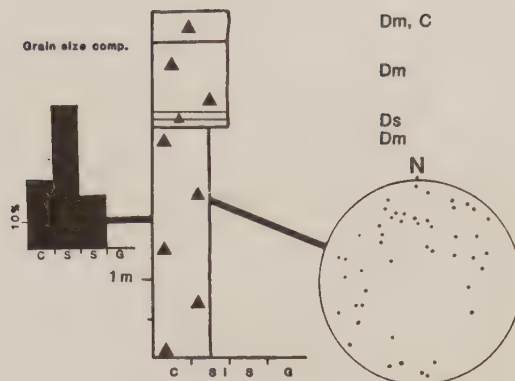


Fig. 52. Log of section 3 at Vilhelmsro.

This bed appears to be a grading zone between over- and underlying diamictons.

1,30 m yellowish sandy silty diamicton with thin winding veins of light gray clayey diamicton (Dm, Ds). There is a faint lamination in the lower part of the bed.

Section 2

Section 2 is situated about 100 m NE of the chapel at Vilhelmsro (Fig. 43). The section starts at the level of lake Vättern (Fig. 51).

7,00 m scree.

0,3 m Dark gray silty diamicton (Dm). It displays many laminae of fine sand.

0,20 m dark gray silty diamicton (Ds). It contains an unusually high amount of sand and gravel. The diamicton shows faint lamination.

5,00 m brownish gray silty clayey diamicton (Dm). It contains cobbles and boulders and there is no visible stratification. The bed is very jointed.

1,10 m yellowish brown poorly sorted silt (Fm). It is jointed in the upper part but not in the lower, where it is very consolidated.

0,60 m redbrown, with light gray spots, sandy silty diamicton (Dm). It is homogeneous with very few clasts.

0,70 m yellowish gray sandy silty diamicton (Dm). It is homogeneous and soft. There are many clasts, mostly rounded or well rounded. In the lower contact the diamicton shows a faint lamination.

0,30 m sandy silty diamicton with organic material (Dm, C).

Section 3

Section 3 is situated about 50 m east of the chapel at Vilhelmsro (Fig. 43). The section starts at the level of lake Vättern (+88,5 m, Fig. 52).

6,00 m scree.

3,00 m Brownish or bluish gray silty clayey diamicton (Dm). It is jointed. The joints are more closely spaced in the upper part of the bed than in the lower. The diamicton is very homogeneous with a few rounded to well rounded clasts. A fabric analysis has been made in the upper part of this bed.

0,20 m stratified silty diamicton (Ds). It is a zone where the underlying diamicton is grading into overlying silty diamicton.

0,90 m yellowish brown silty diamicton. It is

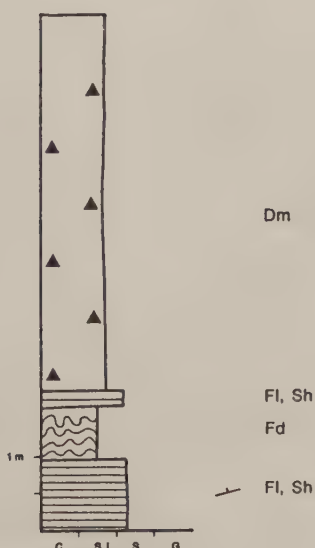


Fig. 53. Log of section 4 at Vilhelmsro.

soft and contains very few clasts. There are thin winding veins of greenish gray or light gray clayey diamicton. The veins sometimes coincide with roots, but the veins have a wide lateral extent. A fabric analysis was made in this bed. (Fig. 52).

0,40 m massive silty diamicton with organic material (Dm,C).

Section 4

Section 4 is situated about 28 m south of section 3 (Fig. 43). The section starts at the level of lake Vättern (+88,5 m, Fig. 53). 2,50 m scree.

0,95 m horizontally laminated fine sand, silt and clay (Fl,Sh). There are some diamicton laminae in the upper part of the bed. There are also some "dropstones" in this part of the bed. The laminae under the "dropstones" are only slightly deformed. Structures around the clasts indicate that they were pushed in a southwesterly direction. Hollows behind (northeast of) the clasts were later filled. The lamination is sometimes folded. There are 32 clay laminae in the bed. About 0,50 m up in the bed the laminae dip 33° towards 348°. A thrust fault on the same level has a fault plane dipping 24° southwest and striking 138-318°.

0,70 m contorted laminated silt and clay (Fd). The bed has been deformed into an almost massive texture. There are five 0,02-0,04 m thick clay laminae in the bed. Just below the clay laminae the underlying silt is coarser than in the rest of the silt laminae. 0,20 m laminated fine sand, silt and clay (Fl, Sh). There are 8 clay laminae in the bed.

5 m gray or grayish brown silty clay diamicton (Dm). The diamicton is highly jointed with iron and manganese precipitations in the fractures.

Section 5

Section 5 is situated about 1,5 m south of section 4 (Fig. 43). The section starts at

the level of lake Vättern (88,5 m, Fig. 54).

0,30 m scree.

0,30 m Contorted horizontally laminated silt and clay (Fl).

0,50 m Contorted horizontally laminated sand silt and diamicton with a few thin laminae of clay (Sh, Fl, Ds).

0,50 m Contorted and folded horizontally laminated fine sand and silt diamicton (Fl, Ds). A fold in the middle of the bed has a fold-axis dipping 4° towards 280° and the axial plane is dipping towards the north.

0,30 m Contorted laminated fine sand, silt and clay (Fd). The sand shows ball and pillow (pseudo nodules) structures (Vesajoki 1982).

0,50 m horizontally laminated silt and diamicton with thin laminae of sand and clay (Fl,Ds).

0,40 m horizontally laminated silt and sand (Sh).

0,60 m horizontally laminated sand, silt and diamicton (Sh,Ds). The laminae are dipping 23° towards 334°. In the bed there is a normal fault. The faultplane dips 15° to the south and strikes 141-321°.

0,60 m laminated silt and clay with thin laminae of sand and diamicton (Fl). In the top of the bed there is a fold with a fold-axis dipping 28° towards 13° and an axial plane dipping towards the north.

scree

Section 6

Section 6 is situated about 6,5 m south of section 5 (Fig. 43). It starts at the level of lake Vättern (+88,5 m, Fig. 55).

3,40 m scree.

0,30 m Laminated sand, silt clay and diamicton (Fl,Ds,Sh). The laminae dip 40° towards 309°.

0,20 m Laminated clay and silt (Fl). There are some thin laminae of fine sand and diamicton. The lamination is very contorted.

0,20 m laminated sand, silt, clay and diamicton (Fl, Ds, Sh). The laminae are displaced by a fault.

0,95 m Laminated clay and diamicton, with thin laminae of silt (Fl,Ds). The clay laminae are about 2 cm thick. The bed is partially very contorted.

0,10 m planar-bedded graded sand and silt (Sg). The bed consists of about 14 normally graded sequences from sand to silt. The lamination displays flame and other water escape structures. The laminae were displaced by a reserved fault. The fault fracture is filled with silt and dips 59° and strikes 17-197°.

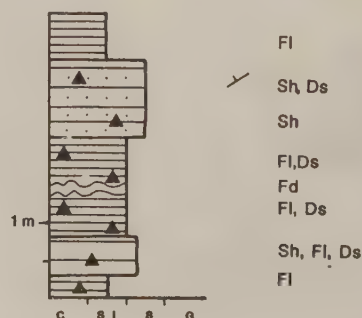


Fig. 54. Log of section 5 at Vilhelmsro.

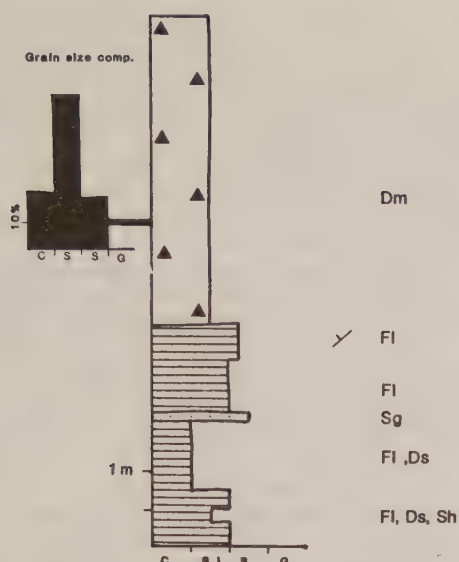


Fig. 55. Log of section 6 at Vilhelmsro.

0,70 m Very contorted laminated silt and clay (Fd). In the lower part of the bed there is a 0,04 m thick lens of contorted fine sand.
0,45 m Laminated fine sand, silt and clay (Fl). There are 15 clay-laminae in the bed. The laminae in the bed are 0,01-0,02 m thick. The bed displays few disturbances. The laminae are dipping 33° towards 320° .
4 m gray silty clayey diamicton (Dm). It is very jointed with iron and manganese oxides precipitations in the fractures.

Section 7

Section 7 is situated about 5 m south of section 6 (Fig. 43). It starts at the level of lake Vättern (+88,5 m, Fig. 56).

0,70 m scree.

1,00 m contorted laminated silt and clay (Fl). The laminae dips 13° towards 52° .

0,15 m fine sand, silt and clay (Fl). An intraclast of silty clay has disturbed the lamination. The laminae dip 6° towards 313° . The lamination is displaced by a thrust fault. The faultplane was dipping 48° to the north and is striking $119-229^\circ$.

0,20 m Laminated fine sand and silty diamicton (Sh, Ds).

0,50 m Massive silty diamicton (Dm).

0,60 m Contorted laminated clay with thin laminae of silt (Fl). There are 10 clay laminae, varying in thickness between 2-5 cm. The most fine-grained material is in the top of each layer.

0,15 m Planar-bedded graded sand and silt (Sg). The bed consists of about 14 normally graded sequences. The laminae in the bed are dipping 19° towards 36° . The stratification is disturbed by flame and other water escape structures. The bed is displaced by one reverse fault and one thrust fault. The reverse fault plane is dipping 64° towards the north and striking $90-270^\circ$. The thrust faultplane dips 28° towards the south and strikes $32-212^\circ$.

1,20 m laminated clay silt and sand (Fl). There are 10 clay laminae in the bed. They are about 10 cm thick in the lower part of

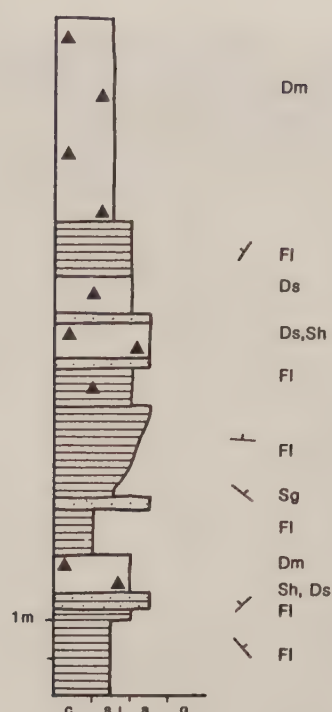


Fig. 56. Log of section 7 at Vilhelmsro.

the bed and become successive thinner upwards, to about 2 cm in the top of the bed. The lamination is contorted in the bottom of the bed. In the upper part of the bed, the laminae are dipping 90° and striking $44-224^\circ$.
0,50 m horizontally laminated sand, silt and clay. (Fl). A drop stone with a diameter of about 4 cm has made only minor disturbance in the underlying laminae. Overlying laminae are conformably bent around the clast showing that the material was horizontally deposited and subsequently displaced. It also indicates that the overlying material has fallen out of suspension.

0,70 m Laminated sand and diamicton (Ds, Sh). There are three thick beds of diamicton, 10, 20 and 30 cm thick, respectively. In the diamicton beds there are thin laminae of sand. Between the diamicton units there is sand with laminae of diamicton. The lamination is dipping 58° towards 321° .

0,50 m Brownish gray silty diamicton (Ds). There are thin lenses of sand in the unit. There are some winding laminae of violet clay in the unit.

0,70 m laminated clay, silt and sand (Fl). In the upper part of the unit there are some laminae of silty diamicton. There are 11 clay laminae in the unit. The laminae are dipping 42° towards 304° .
2,8 m gray silty clay diamicton (Dm). It is jointed with iron and manganese oxides precipitated in the fractures.

Comments: In the upper part of this section there is an extension joint penetrating the Rosenlund diamicton (the jointed diamicton) and the upper part of Kaptensbo beds. The fracture is 3-4 cm wide and filled with rhythmically laminated sand and clay. There are five clay laminae, including the contact with surrounding sediments. The sandlayers become thicker upwards (Fig. 57). There are

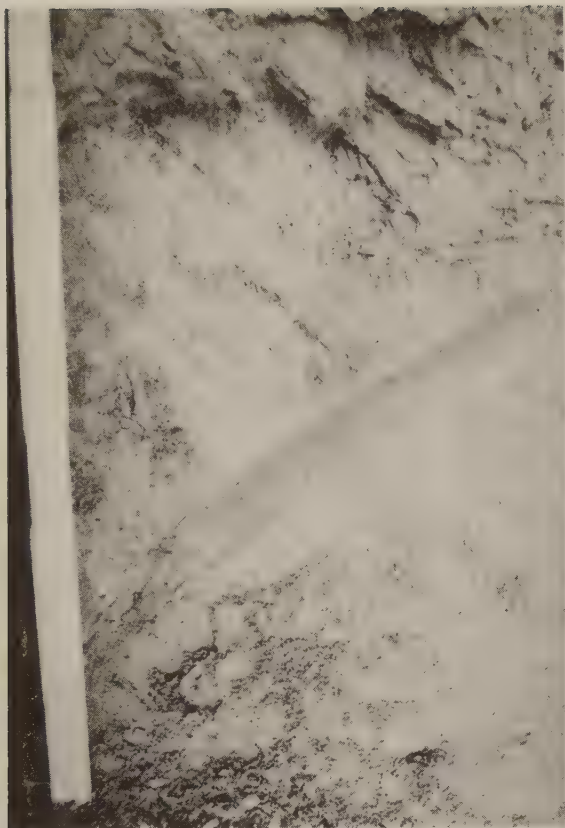


Fig. 57. A wedge filled with laminated sand silt and clay in section 7 at Vilhelmsro.

no signs of movement along the fracture.

Section 8

Section 8 is situated about 4 m south of section 7 (Fig. 43). It starts from the level of lake Vättern (+88,5 m, Fig. 58).

1,00 m scree.

0,70 Contorted laminated sand, silt and clay (Fl). The clay is often deformed into lenses or balls. This bed is possible to correlate (in the field) to the lowest bed in section 7.

0,45 m horizontally laminated sand, silt and diamicton (Sh,Ds). The diamicton laminae become thicker upwards. The laminae are dipping 11° towards 43°.

0,35 m Massive silty diamicton, with only a few lenses of fine sand (Dm). This bed is correlated (in the field) with section 7.

0,70 m laminated clay, silt and sand (Fl,Sh). There are 9 clay laminae in the bed, varying in thickness between 1 and 10 cm. The clay is thickest in the lower part of the bed and gets thinner upwards. The most fine-grained clay is in the top of each layer. The lamination is disturbed by waterescape structures.

0,20 m planar-bedded normal graded sand and silt (Sg). The lamination is disturbed by flame and other waterescape structures. The laminae are dipping 11° towards 66°. This bed is possible to correlate (in the field) with section 7.

0,40 m contorted laminated clay, sand and

silt (Fl). There are 7 clay laminae in the unit.

0,50 m breccia consisting of clay balls, lumps of laminated sand, silt and diamicton (Fd). There are many clasts in the bed. (This unit is in the middle of a fold).

0,50 m contorted laminated clay, silt and sand (Fd). There are 7 clay laminae in the bed. There is a fault in the bed dipping 70° to the NW and striking 45-225°.

0,15 m planar-bedded normal graded sand and silt (Sg). The silt becomes less frequent upwards. The lamination is dipping 76° towards 111°.

The bed is displaced by a fault, with a fault plane dipping 77° and striking 23-203°.

0,65 m laminated clay with thin laminae of silt (Fl). There are 5 clay laminae in the bed.

0,60 horizontally laminated sand, silt and clay (Sh, Fl). The lamination is less disturbed than usual. The laminae are dipping 64° towards 302°. An extension joint fracture cuts through the unit. The fracture is filled with clay.

1,50 m horizontally laminated fine sand and diamicton (Sh,Ds). In the middle of the unit there are three thick beds of diamicton. The diamicton is sandy with few clasts. In the upper part of the bed there is a cluster of dropstones. The dropstones have deformed underlying lamination but the laminae are only bent downwards a few millimeters.

The laminae are dipping 44° towards 22°. Some sand laminae folded.

1,80 m gray silty clayey diamicton (Dm). The bed is jointed with iron and manganese precipitations in the fractures. There are some clay filled extension joints in the unit. In the lower part of the unit there are some totally deformed laminae of silt and

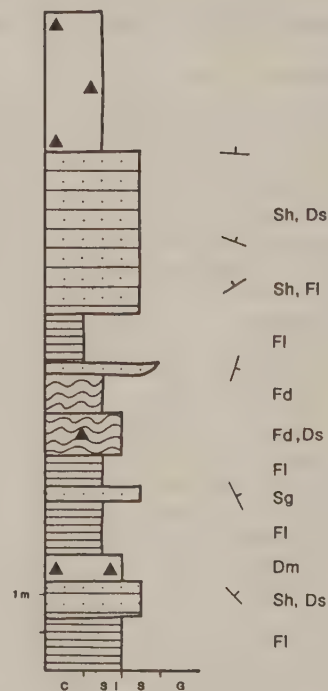


Fig. 58. Log of section 8 at Vilhelmsro.

clay. The contact with underlying sediment is dipping 25° towards 356° .

Section 9

Section 9 is situated about 5 m south of section 8 (Fig. 43). It starts at the level of lake Vättern (+88,5 m, Figs. 59 and 60).

0,20 m scree.

0,70 stratified clayey sandy diamict (Ds--Dm--Ds). In the lower part of the bed the diamict displays a faint lamination. In the upper part of the bed the lamination is more pronounced with alternating lamination of sandy diamict and clayey diamict. The stratification is contorted and folded (Fig. 60). In the middle of the bed there is a fold with a foldaxis dipping 24° towards 310° and the axial plane dips to the north. The non-contorted laminae are dipping 9° towards 358° . One fabric analysis was made in the bed. The stratified diamict is grading into the overlying bed.

0,7 m contorted planar-bedded normal graded sand and silt (Sg). 0,1 m contorted laminated silt and clay (Fl).

0,80 m contorted laminated fine sand, silt, clay and diamict (Fl,Ds).

0,30 m Massive sandy diamict with few thin sand lenses (Dm).

0,30 horizontally laminated fine sand, silt and clay (Fl).

4,20 m very contorted silt and clay (Fd). About 1,4 and 2,1 m up in the bed there are some laminae of sand.

0,20 m contorted laminated fine sand and clay (Fd). The laminae are dipping 80° towards 282° .

1,00 m contorted horizontally laminated fine sand and silt with balls of clay (Fl).

0,40 m contorted horizontally laminated sand and fine sand with thin laminae of sandy diamict (Fl).

0,50 m contorted laminated fine sand and clay (Fl).

0,40 m gray silty clayey diamict (Dm). It is jointed with iron and manganese precipitations in the fracture.

--scree

Discussion of section 5-9

In the area of sections 5-9 a big fold was later found (Fig. 49). The fold probably continues both towards the south and towards the

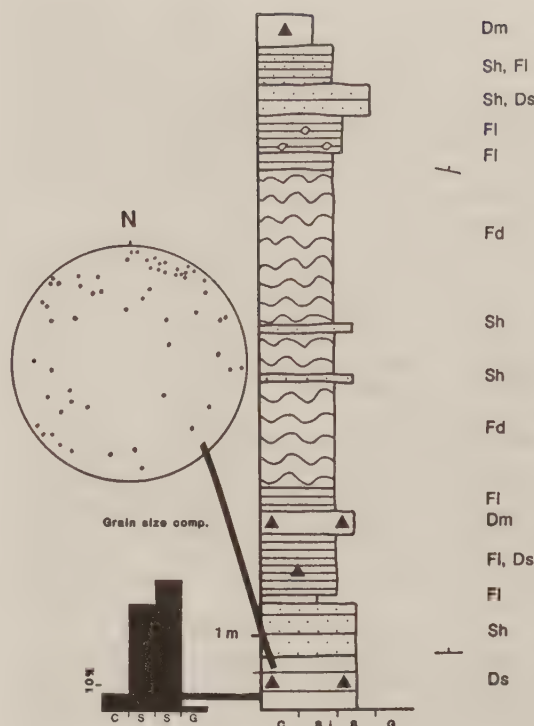


Fig. 59. Log of section 9 at Vilhelmsro.

north of the sector, how far is not known. The dip and direction of the foldaxes were measured at several places: 12° towards 58° , 20° towards 48° and 16° towards 30° , with a mean of 16° towards 45° . The axial planes are dipping towards the north.

Due to the folding, the stratigraphy in the sections is partly repeated. In section 10-16 it is not clear how much is repeated.

In the top of section 6-8, upwards and towards the south, successively more and more of the Kaptensbo beds are incorporated in the Rosenlund diamict. For example, in section 7 there is a 0,7 m thick unit of horizontally laminated clay, silt and sand, below the Rosenlund diamict. About 4 m to the south, this unit is missing. When following the contact between the units it is possible to see that the unit has been incorporated in the Rosenlund diamict. This indicates that the



Fig. 60. a) the lower part of section 9 b) a close up of a small fold.

Rosenlund diamicton or the glacier depositing it, moved towards the south. The movement could only have been caused by glaciotectonic pressure from a northern sector. This indicates that at least the lower part of the Rosenlund diamicton is a deformed sediment or a till, deposited in a subglacial environment, with an ice-movement from a northern sector.

In the upper part of the Kaptensbo beds in section 7 and 8, about 1 m below the contact to the Rosenlund diamicton, there are many small folds in a unit of laminated sand. The fold axes dip 50° towards 12°, 40° towards 12° and 30° towards 270°. The first two axial planes dip towards the west and the third towards the north.

The extension joints, filled with sand or clay, cutting through the Rosenlund diamicton and the upper part of the Kaptensbo beds, indicate that the Rosenlund diamicton and the Kaptensbo beds were subjected to tension after these units were deposited. Extension joints often go together with folding (Hobbs et al 1976).

The big fold indicates a glaciotectonic pressure from an eastern sector, but there are indications suggesting that the Rosenlund diamicton was deposited from a northern sector.

This indicates that two glaciotectonic events might have influenced the sediments at Vilhelmsro.

Section 10

Section 10 is situated about 6 m south of section 9 (Fig. 43). It starts at the level of lake Vättern (+88,5 m, Fig. 61).

2,90 m scree.

0,35 m stratified sandy and clayey diamicton with thin laminae of sand, silt and clay (Ds, Fl). The bed looks like the upper part of the lowest bed in section 9.

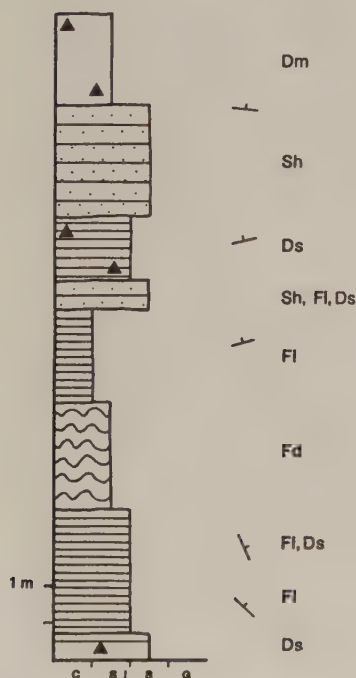


Fig. 61. Log of section 10 at Vilhelmsro.

0,70 m laminated fine sand and silt (Fl). There are two clay laminae in the bed. The laminae are dipping 24° towards 38°.

0,90 m laminated clay silt and diamicton (Fl, Ds). Silt is the dominating fraction. The laminae are dipping 12° towards 76°.

1,40 m very contorted clay and silt (Fd). No lamination is visible.

1,20 m laminated clay with thin silt laminae (Fl). The clay laminae are 2 cm thick and are dipping 80° towards 284°. In the middle of the bed there is a 1-2 cm wide, sandfilled extension joint. The fracture ends in a ramification looking like the claw of a bird.

0,40 m horizontally laminated sand, silt, clay and diamicton (Sh, Fl, Ds).

0,70 m stratified diamicton with thin silt laminae (Ds, Fl). The laminae are dipping 86° towards 282°.

1,20 m horizontally laminated sand and silt (Sh). In the upper part of the bed the laminae are standing vertical. In the lower part of the bed there is a sandfilled joint. At first, the fracture follows the lamination, but further down it cuts the laminae and becomes almost vertical. The fracture is dipping 78° and striking 80-260°. There seems to have been movement along the joint but it has not been possible to find out in what direction.

1,4 m gray silty clayey diamicton. It is jointed with iron and manganese precipitations in the fractures. The contact with underlying sediments is concordant and dipping 76° towards 285°.

Section 11

Section 11 is situated about 5 m south of section 10 (Fig. 43). It starts at the level

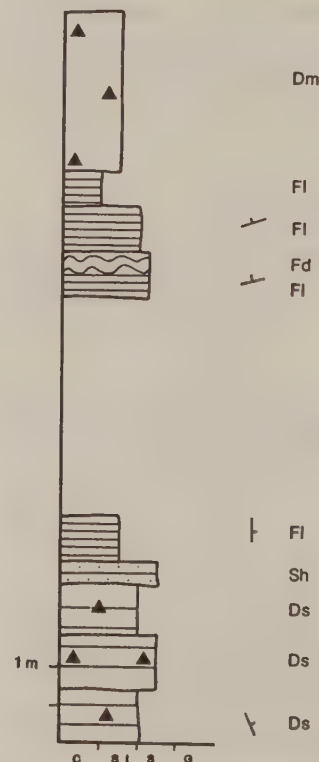


Fig. 62. Log of section 11 at Vilhelmsro.

of lake Vättern (+88,5 m, Fig. 62).

1,75 m scree.

0,70 m stratified sandy diamicton (Ds). There are thin laminae of clay and silt in the unit. The laminae are dipping 4° towards 345° .

0,70 m stratified sandy diamicton (Ds).

0,65 m stratified silty sandy and silty clayey diamicton (Ds).

0,30 m very contorted laminated sand and silt (Fd).

0,60 m horizontally laminated clay silt and diamicton (Fl). The laminae are dipping 12° towards 87° .

2,80 scree.

0,30 m horizontally laminated fine sand, silt clay and diamicton (Fl). The laminae are dipping 80° towards 283° .

0,30 m contorted horizontally laminated fine sand, silt, clay and diamicton (Fd).

0,60 m rhythmically laminated fine sand, silt and clay (Fl). The most fine-grained clay lies in the top of each sequence. The laminae are dipping 80° towards 286° .

0,40 m laminated clay with thin laminae of silt (Fl). The bed is jointed.

2,10 m massive gray silty clayey diamicton (Dm). The bed is very jointed.

--scree.

Section 12

Section 12 is situated about 4 m south of section 11 (Fig. 43). It starts at the level of lake Vättern (+88,5 m, Fig. 63).

6,00 m scree.

0,70 m laminated diamicton with thin laminae of sand, silt and clay (Ds, Fl).

0,70 m laminated fine sand, silt and clay (Fl). In the top of the bed there is a lamina of silty diamicton. The lamina is dipping 78° towards 274° .

0,35 m horizontally laminated sand (Sh). The laminae are dipping 88° towards 267° .

0,15 m laminated clay and silt (Fl).

0,20 m horizontally slightly contorted sand and silt (Sh). The laminae are dipping 63° towards 285° .

0,50 m very contorted clay with thin laminae of silt (Fd).

2,10 m very jointed gray silty clayey diamicton (Dm).

--scree

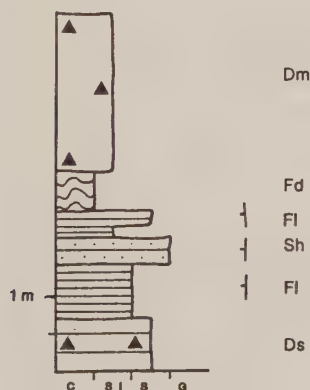


Fig. 63. Log of section 12 at Vilhelmsro.

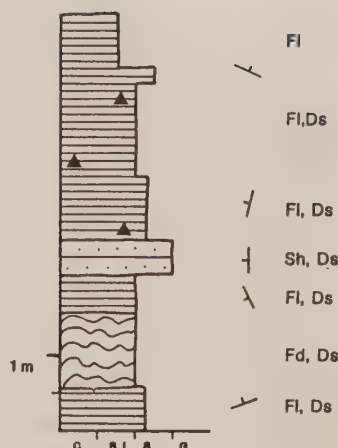


Fig. 64. Log of section 13 at Vilhelmsro.

Section 13

Section 13 is situated about 4 m south of section 12 (Fig. 43). It starts at the level of lake Vättern (Fig. 64). Between section 12 and 13 there is a small cut stratigraphically below section 13. This small cut consists of very contorted laminated sand, silt, clay and diamicton (Fl, Ds). The laminae are dipping 31° towards 30° .

4,90 m scree.

0,55 m very contorted fine sand and silty diamicton (Fl, Ds). In the top of the bed the laminae are dipping 7° towards 341° .

1,00 m brecciated laminated silt and diamicton (Fd, Ds)

0,50 m laminated fine sand, silt and diamicton (Fl, Ds). The laminae are dipping 88° towards 248° .

0,45 m horizontally laminated sand and sandy diamicton (Sh, Ds). The laminae are dipping 86° towards 269° .

0,85 m slightly contorted laminated fine sand, silt and diamicton (Fl, Ds). The laminae are dipping 62° towards 283° .

1,20 m very contorted laminated silt and silty diamicton (Fl, Ds).

0,20 m contorted laminated fine sand and silt (Fl). The laminae are dipping 29° towards 65° .

0,70 m very jointed laminated clayey silt (Fl).

- scree.

Section 14

Section 14 is situated about 3 m south of section 13 (Fig. 43). It starts at the level of lake Vättern (+88,5 m, Fig. 65).

2,80 m scree.

0,60 m very contorted laminated silt, clay and diamicton (Fl, Ds).

0,30 m laminated silty diamicton (Dm). In the middle of the bed there is a lamina of sand dipping 8° towards 176° .

2,10 m laminated fine sand, silt and diamicton (Fl, Ds). The laminae are dipping 74° towards 288° . In the middle of the bed there is a small fold with a fold axis dipping 36° towards 141° . The axial plane is dipping towards the east.

0,50 m contorted laminated sand, silt and clay (Fd). The laminae are folded with a fol-

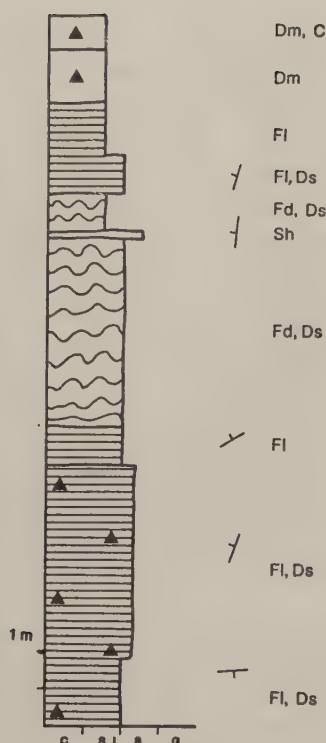


Fig. 65. Log of section 14 at Vilhelmsro.

daxis dipping 66° towards 330° . The axial plane is dipping towards the northeast.

2,50 m very contorted laminated silt and stratified silty diamicton (Fd, Ds).

0,10 m horizontally laminated sand and silt (Sh). The laminae are dipping 54° towards 277° . The laminae are displaced by two normal flexure faults. One of the faultplanes dips 33° towards the north and strikes $150-330^{\circ}$.

0,50 m very contorted laminated clay, silt and diamicton (Fd, Ds).

0,50 m contorted laminated clay, sand, silt and diamicton (Fl, Ds). The laminae are dipping 16° towards 292° .

0,70 m very jointed laminated clay and silt (Fl).

0,70 m very jointed gray silty clayey diamicton (Dm).

0,50 massive silty clayey diamicton with organic material (Dm, C).

Section 15

Section 15 is situated about 5 m south of section 14 (Fig. 43). It starts at the level of lake Vättern (+88,5 m, Fig. 66).

2,80 m scree.

0,30 m laminated fine sand with a few thin laminae of silt and diamicton (Fl).

1,80 m brecciated silt and fine sand (Fd).

0,70 m gray silty diamicton with thin laminae of silt (Ds, Fl).

0,60 m laminated clay and silt (Fl). The lamination is folded and disturbed.

0,40 m slightly contorted laminated fine sand, silt and clay (Fl). The laminae are dipping 30° towards 254° .

0,70 m jointed laminated silt and clay (Fl).

3,90 m very jointed silty clay diamicton (Dm).

0,70 m scree.

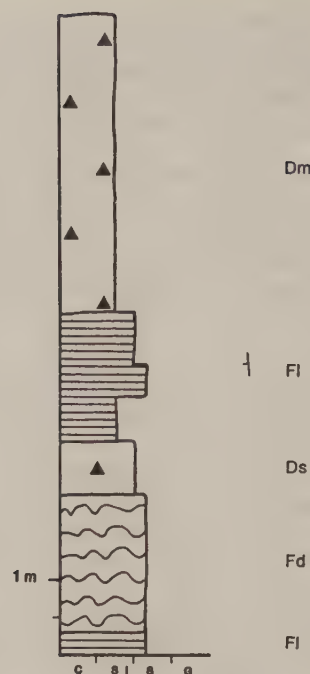


Fig. 66. Log of section 15 at Vilhelmsro.

Section 16

Section 16 is situated about 7 m south of section 15 (Fig. 43). The section starts at the level of lake Vättern (+88,5 m, Fig. 67).

5,7 m scree.

0,70 m laminated clay and silt (Fl). The laminae are dipping 11° towards 44° (Fl).

5,70 m very jointed silty clayey diamicton (Dm). There are iron and manganese precipitations in the fractures.

0,10 m contorted horizontally laminated fine sand (Sh).

0,70 m redbrown soft, sandy, silty diamicton (Dm).

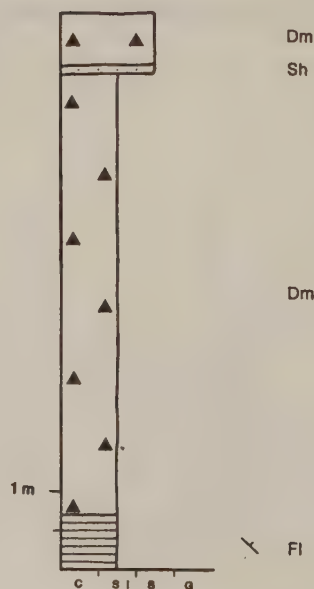


Fig. 67. Log of section 16 at Vilhelmsro.

Section 17

Section 17 is situated about 150 m west of section 1 and 150 m north of the chapel at Vilhelmsro (Fig. 43). The top of the section starts at about +109 m which is about 9 m above the top of section 1.

- scree.

2,5 m redbrown clayey sandy diamicton with light or greenish light gray, thin winding veins of a more clay rich diamicton (Dm). A sample is taken about 1 m up in the section. The diamicton has the same rock fragment composition as the Öxnehaga diamicton in the vicinity.

7:2:3 Discussion

Kaptensbo beds

The lowest and dominating sediments at Vilhelmsro are the Kaptensbo beds. These sediments consist of laminated sand, silt, clay and diamicton. Dropstones, up to cobble size, are quite common. Intraclasts have also been observed. Some laminae of sand and silt display normal graded bedding. These laminae are often contorted and display flame- and other waterscape structures. The silt is laminated with abundant deformation structures due to fluidized flow and glaciotectionic shear. The clay is laminated and often very contorted. Individual clay beds are often surprisingly thick (up to 30 cm). The diamicton is sandy silty or silty and is usually stratified. Thick massive beds have also been observed. The diamicton contains few clasts. The clasts are mostly well rounded. The diamicton units often have thin laminae of sand, silt and clay.

One fabric analysis was made in the stratified diamicton about 30 cm above lake Vättern (Fig. 59). It shows a weak preferred orientation of clasts long axes, around 15°, which is the same as the dip of the stratification of the diamicton.

In the lower part of the Kaptensbo beds the laminae are dipping 4-30° towards the northeast (Fig. 60). In the upper part of the bed the laminae are dipping steeply (up to 90°) towards the northwest. Between the laminae with a northeasterly dip and those with a northwesterly dip there is a zone of very deformed sediments. The originally horizontally laminated sediments are sometimes totally brecciated. The fold (Fig. 49) confirms this.

Interpretation: The laminated clay and fine silt indicate that the Kaptensbo beds were deposited in a glaciolacustrine environment and originally horizontally laminated. The northeasterly dip in the lower part of the unit could have been caused by subsidence from melting buried ice, sliding on the bedrock/sediment interface, or by glaciotectionic pressure.

The sections at Vilhelmsro are situated about 600 m east of the steep bedrock cliff of the western faultzone of the Vättern basin (Figs. 4 and 5). The laminae in the upper part of the sections at Vilhelmsro are dipping steeply towards the west, northwest or in a few cases towards the north. It is not likely that these high dips were caused by subsidence of buried ice lying between the site and the bedrock wall.

The foldaxes in the big fold also indicate

that the Kaptensbo beds were stressed by pressure from southeast or east. According to the striae in the vicinity the last ice movement in the area was from an eastern sector. The deformation, the folding of the unit and the brecciated zone were probably caused by glaciotectionic pressure from east or southeast.

The texture of the Kaptensbo beds are shown in Fig. 59. The analysis shows a high sand and silt content. The diamicton in the Kaptensbo beds has less fines than the Rosenlund diamicton, but is usually more fine-grained than the Öxnehaga diamicton.

The rock fragment composition is about 70% sandstone and shale from the Visingsö Group of Rocks. Some Paleozoic limestones have also been observed. The sedimentary rock content is about 10% lower than that in the Rosenlund diamicton, but about 10% higher than that in the Öxnehaga diamicton.

The diamicton units in the Kaptensbo beds could have been deposited in two different ways. One is by debris flow, the other is by undermelting of a floating glacier, an iceshelf or by icebergs. A combination of the processes is also possible. If debris flow is the main sedimentary process for the diamicton beds at Vilhelmsro, there are two possible material sources. The debris flow started either as a subaqueous slump or slide of recently depositional material on the steep slopes of the Vättern basin, or the material originated from a glacier terminating north of Vilhelmsro. Neither the texture nor the rock fragment composition give a clear indication as to what process was dominating. However, some foldstructures around clasts in the lowest part of the sections indicate debris flow from the north, suggesting debris flow emanates from debris aggraded under a floating glacier or in front of a grounded ice margin (Hicock et al 1981). Compared with the overlying Rosenlund diamicton, the stratified diamicton in the Kaptensbo beds is winnowed. The fines (clay and fine silt) are missing (Fig. 59). A diamicton is winnowed both in the debris flow process and by undermelting, but it should be more obvious in the undermelt process. The thin laminae of sand, silt and clay in the diamicton units were more likely formed by the undermelt process, but there are thicker sand units, which are deposited by turbidity currents.

In the lower part of the section 9 (Fig. 59) there is an alternating lamination of sandy diamicton and clayey diamicton grading into an overlying unit of graded bedded sand and silt. The alternating lamination favors the undermelt alternative. It is not likely that a debris flow would display such a rhythmic appearance with sandy diamicton succeeded by clayey diamicton. The fabric in the stratified diamicton favors the debris flow model. Debris flows could display a good preferred orientation (Carter 1975, Enos 1973, Lewis 1981).

Undermelt diamicton often shows a random or a poor preferred orientation of clasts long axes (Gravenor et al 1984).

The diamicton in the lowest part of section 9 appears to have been deposited as an undermelt diamicton by a rain out process under a floating glacier, an ice shelf or by icebergs. Upwards into the sections, debris flow was the most likely depositing process for the diamicton units.

The units of sand and coarse silt are often graded and show waterescape structures. These units are probably deposited by low concentration turbidity currents (Middleton 1967).

Liquified flow and fluidized flow are possible depositional processes, especially for the massive and faintly laminated sand and silt laminae. The sand and coarse silt could have been deposited by grain flow or modified grain flow (Lowe 1976a). The fine silt and clay was deposited from fall out of suspension during periods of low energy water.

It is likely the Kaptensbo beds are deposited by a combination of undermelting and sediment gravity flow processes.

Rosenlund diamicton

The Kaptensbo beds are conformably superimposed by the Rosenlund diamicton.

Texture: The lowest part of the Rosenlund diamicton consists of very deformed sediments, upwards becoming a very homogeneous diamicton. It is possible to see how parts of the Kaptensbo beds were incorporated in the Rosenlund diamicton. The grain size composition of the diamicton is homogeneous with 15-39% clay and about 45% silt.

Joints: The Rosenlund diamicton is jointed in the same way as in Rosenlunds bankar. The dip and strike of the subvertical and the sub-horizontal joint systems are presented in Fig. 68.

Rock fragment composition: The composition of the Rosenlund diamicton varies between 72 and 87% with a mean of 79% of sedimentary rocks from the Visingsö Group. That is higher than the sedimentary rock content of the Kaptensbo beds but about 10% lower than the Rosenlund diamicton in the eastern and southern part of the basin.

Fabric: Two fabric analyses are presented in Fig. 69. One analysis was made about 50 m south of section 16, about 4 m below the ground surface. The fabric shows two clusters about 90° apart, one at 45° and the other at 315°. At this spot it is not possible to examine if the diamicton bed is horizontal or if it dips in any direction.

The other analysis was made at section 3 about 2 m below the ground (Fig. 52). This analysis displays no preferred orientation of clasts long axes, except that there are no particles orientated in a southeasterly sector.

The bedding of underlying sediments in the vicinity dips about 45° towards the northwest and there are indications that the unit is displaced after the diamicton was deposited.

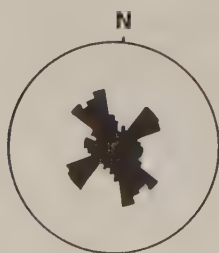


Fig. 68. The strike of subvertical joints in the Rosenlund diamicton at Vilhelmsro.



Fig. 69. The dip and direction of clast long axis in the Rosenlund diamicton at Vilhelmsro. The analyses were made in the same area as the joint analyses.

Interpretation: The grain size composition and the shape of the clasts indicate that the Rosenlund diamicton consists of reworked glaciolacustrine- and glaciofluvial sediments, which is also shown in the incorporation of sediments.

The sole of the diamicton often dips steeply towards the north, northwest or west. A diamicton with more than 75% cohesive material could not possibly have been deposited in this position, except if the unit was supported. The incorporation of sediments indicate that the substrate was horizontal before the Rosenlund diamicton was deposited. It is obvious that the Kaptensbo beds and at least the lower part of the Rosenlund diamicton were displaced after sedimentation, because of high and similar dip of both units.

The topographical position of the site at Vilhelmsro indicates two possible depositional environments for the Rosenlund diamicton. One is subaquatic and the other is deposition below a glacier. In the subaquatic environment there are three possible processes of sedimentation. 1) debris flow, 2) droppings from icebergs, 3) material raining out from a floating glacier or from an iceshelf standing about 1 m (Gravenor et al 1984, May 1977) or less above the bottom of the lake.

The thick beds, the homogeneous texture, the rock fragment composition, the lack of structures, the few sediment laminae or lenses and the poor fabric indicate that the Rosenlund diamicton (at Vilhelmsro) was not deposited by subaqueous debris flow.

For topographical reasons, an ice dammed lake in the Vättern basin (Fig. 3) would reach about +220 m, which is about 130 m higher than the present lake level. Material released from lake ice, from icebergs or from an ice shelf floating in deep water, should have been sorted due to different settling velocities of the different fractions. A dropped sediment in deep water should display a lot of laminae and lenses of sorted material. The steep slopes at the Vättern basin should have produced a number of turbidity currents depositing sorted material in the basin. One argument favoring dropped sediment, is the high dip of clasts long axes in the fabric analyses at Vilhelmsro, but the high angles could be due to secondary displacement of the Rosenlund diamicton.

The third sedimentation process is related to the sediment drop from icebergs. It is called undermelt or rain-out material. The debris

was dropped from the sole of floating glacier into a water, in this case the water depth is not exceeding one meter. The undermelt diamicton described in the literature (Gravenor et al 1984, Rocha-Campos 1983) are usually very thick and massive or display faint lamination. Undermelt diamicton has fine-grained texture and usually contains a lot of intraclasts. Extrabasinal clasts are usually rounded or well rounded. The fabric is usually poorly developed. The description of the undermelt diamicton fits well with the Rosenlund diamicton.

Subglacial deposition of the Rosenlund diamicton is also possible. Theoretically there are three different depositional processes possible for the Rosenlund diamicton. 1) passive melting out of debris from the lowest part of a stagnant ice body, 2) deposition by lodgement, 3) glaciotectionic deformation of already deposited sediments.

1) The meltout process is very slow. The geothermal heat is capable of melting about 6 mm / unit area of ice in one year, if the glacier is at the pressure melting point. If the ice in the lower part of the glacier contains 50% debris (which is extremely high, Lawson 1979), it would have taken about 2000 years to melt out the Rosenlund diamicton at Vilhelmsro. Basal meltout till described in the literature (Shaw 1979, Haldorsen 1981, Haldorsen and Shaw 1982, Gibbard 1980) always displays many lenses and laminae of sorted sediments, which is not the case in the Rosenlund diamicton. The basal meltout process is not likely for the Rosenlund diamicton.

2. The lodgement process means sedimentation grain by grain, when the frictional force against the sole exceeds the yield strength of the glacier ice. Lodgement till is usually massive, contains more rounded clasts than other types of tills in the area. It is more fine-grained than other till types in area. Lodgement tills have very good fabric with clasts long axes in the transport direction (Boulton 1970b, 1971). Lodgement till is usually deposited in relatively thin (1-3 m) beds. The Rosenlund diamicton does not fit the lodgement till depositional model.

3) Glaciotectionic deformation of already deposited sediments: If sediments like the Kaptensbo beds are deformed and totally mixed it might look like the Rosenlund diamicton. However it is not likely that a mixing would result in such a thick bed of homogeneous diamicton just by deforming a laminated glaciolacustrine sediment. There should be some remnants of laminated sediments somewhere in the unit.

Conclusions: Undermelting is the most likely depositional process for the Rosenlund diamicton.

The material was dropped from the sole of a glacier floating in water. The water column between the bottom and the sole of the glacier was probably less than one meter. From time to time the glacier grounded (perhaps depositing some lodgement till) and deformed and sheared underlying undermelt diamicton.

Öxnehaga diamicton

At some sections at Vilhelmsro, the Rosenlund diamicton is superimposed by the Öxnehaga diamicton. Sometimes there are thin beds of

sorted sediments (mostly sand) between the two diamicton beds.

Texture: The Öxnehaga diamicton is sandy silty or silty. It is soft and contains very few clasts. The clasts are usually rounded or well rounded. The diamicton is redbrown and sometimes stratified especially in the lower part of the bed. The Öxnehaga diamicton is heterogeneous and often consists of many beds of diamicton, separated by thin laminae of sand.

Rock fragment composition: The composition of the Öxnehaga diamicton is about 63% sedimentary rocks from the Visingsö Group and about 37% crystalline rocks. The percentage of sedimentary rocks is about 10% lower than the diamicton units in the Kaptensbo beds, and about 20% lower than the Rosenlund diamicton.

Fabric: One fabric analysis was made at section 3 (Fig. 52). It shows an almost random orientation of clasts long axes with low dips. In this section the Öxnehaga diamicton seems to lie conformably over the Rosenlund diamicton, indicating that the Öxnehaga diamicton was deformed at the same time as the Rosenlund diamicton and the Kaptensbo beds.

Interpretation: The rock fragment composition of the Öxnehaga diamicton indicates a different source of material for the Öxnehaga diamicton as compared to the Rosenlund diamicton. This can be explained in three different ways.

1. The material is brought by debris flows from the steep western slope of the Vättern basin. This would give the Öxnehaga diamicton a higher content of crystalline rocks. The rock fragment composition should be like the diamicton in the western slopes of lake Vättern west of Vilhelmsro. The diamicton at Dalvik and Samset (Fig. 144) about 3-4 km to the southwest have approximately the same rock fragment composition as the Öxnehaga diamicton at Vilhelmsro.

2. The Öxnehaga diamicton can be composed of englacially long transported debris, i.e. the debris are transported higher up in the glacier. This leads to the conclusion that the material was deposited by debris flow from the front of the glacier. Superficial melt-out is also possible, but this depositional process is not likely in a deep lake like lake Vättern.

3. The third way of getting a "new" rock fragment composition is a new glacier overriding the area. This glacier ought to have had a different transport direction in order to bring in "new" material. This "new" material was most likely eroded at the base of the glacier, thus the material was transported at the base of the ice and deposited as lodgement or basal meltout till. Basal meltout is not likely to be the dominating depositional process in a deep lake like the Vättern basin.

Lodgement is supposed to display a good preferred orientation of clasts long axes, which is not the case for the Öxnehaga diamicton at Vilhelmsro.

Conclusion: At Vilhelmsro, most parts of the Öxnehaga diamicton was deposited by debris flows. It is possible that the beds were deformed by glaciotectionic pressure and the upper part of the bed was deposited as a till.

In section 17 the Öxnehaga diamicton is more

homogeneous and displays no sediment lenses. It has a higher content of gravel and clay and is less sorted than the Öxnehaga diamiction at sections 2 and 3. It is a possibility that a floating glacier in the Vättern basin grounded in the higher parts of the basin but not in the lower. It is possible that the upper part of the diamiction is a lodgement till and that the lower part of the diamiction was deposited by undermelt or debris flow processes.

7:2:4 Conclusions

The Kaptensbo beds were deposited in a glaciolacustrine environment with icebergs, an iceshelf or a floating glacier dropping debris. The fines were deposited from suspension. The coarse silt and the sand were deposited by low concentration turbidity currents (Middleton 1967) or other sediment gravity flow processes (Lowe 1979). The diamiction beds were probably deposited by debris flows.

The Rosenlund diamiction consists of reworked glaciolacustrine sediments. Material from the Kaptensbo beds has been incorporated in the Rosenlund diamiction, which indicates that the Rosenlund diamiction is of subglacier origin. Before the glacier eroded the Kaptensbo beds they were in a horizontal position. At least the lower part of the Rosenlund diamiction was deposited in a horizontal position or close to the horizontal, because a cohesive sediment is not deposited in a slope with a angle of about 75° .

The incorporation and deformation in the Kaptensbo beds/Rosenlund diamiction interface suggests that some part of the Rosenlund diamiction was deposited in a subglacial position.

The lower stratified part of the Öxnehaga diamiction was deposited by a rain-out process or by debris flows.

Both the Kaptensbo beds and the Rosenlund diamiction are involved in a big fold with foldaxes striking about $45-225^\circ$, indicating a glaciotectionic pressure from the southeast (or the northwest but no other indications of an ice-movement from the northwest have been found in the investigation area). Extension joints in both the Kaptensbo beds and the Rosenlund diamiction postdate the folding. The joints are perhaps rebound fractures of the fold.

The folding of the Kaptensbo beds and the Rosenlund diamiction is probably of glaciotectionic origin. The deformation occurred either when the upper part of the Rosenlund diamiction was deposited or when the Öxnehaga diamiction was deposited.

The lower part of the Rosenlund diamiction displays a transport direction towards the south, but the big fold indicates a direction of shear towards a western sector, which favors the deformation alternative when the Öxnehaga diamiction was deposited.

On the western side of lake Vättern the youngest striae are pointing towards a western sector. It is likely that the fold is formed by the same glacier that eroded these striae.

The sediment at Vilhelmsro indicates that two glaciers passed and deformed the sediments. The first time, material from the Kaptensbo beds was incorporated in the Rosenlund diamiction and the second time the Kaptensbo

beds and the Rosenlund diamiction were folded and displaced, perhaps when the upper part of the Öxnehaga diamiction was deposited.

7:3 Kaptensbo

The site is situated about 400 m south of the chapel at Vilhelmsro (Fig. 43). Here the coastal cliff is about 20 m high. Two long and six shorter sections have been described. The northernmost section (section 1) is situated about 50 m south of the outlet of the rivulet Vilhelmsrobäcken. The section starts at the level of lake Vättern (+88,5 m). Section 8 is about 200 m to the south.

7:3:1 Sections

Section 1

Section 1 is situated about 50 m south of the outlet of the rivulet Vilhelmsrobäcken (Fig.43). The section starts at the level of lake Vättern (Fig.70).

About 5 m south of the section there is a big fold. The foldaxis dips 2° towards 38° and the axial plane dips towards the northwest.

0,2 m scree.

0,6 m contorted laminated clay and diamiction (Fl, Ds). There are thin laminae of sand in the unit. In the bed there is a fold with the foldaxis dipping 17° towards 55° and the axial plane dipping towards the northwest. The unit is very compact.

0,2 m stratified sandy diamiction with thin laminae of sand and silt (Ds, Fl). There are many clasts in the bed. The upper contact is interbedded.

0,3 m wavy laminated clay, silt and fine sand (Fl). There are laminae of sandy diamiction in the lower part of the unit.

1,3 m stratified silty diamiction with slightly deformed lenses of sand (Ds, Sd). The sand is often folded. The foldaxis in one of the lenses dips 2° towards 8° .

1,7 m alternating horizontally laminated sand and silty diamiction (Sh, Ds). The thickness of the diamiction laminae increases upwards.

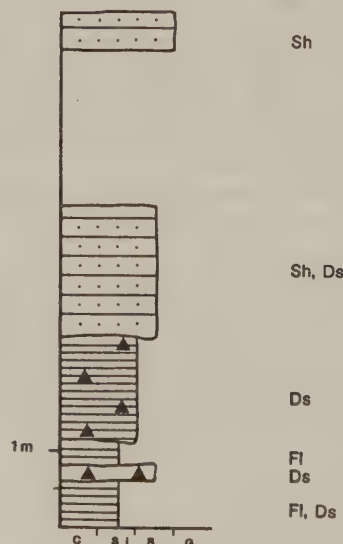


Fig. 70. Log of section 1 at Kaptensbo.



Fig. 71. An intraclast in section 1.

There are many dropstones in the unit, causing small deformation of underlying sediments. In the upper part of the bed there is an intraclast, with a diameter of about 0,4 m, of sandy diamicton (Fig. 71). The texture of the intraclast looks like a sandy diamicton found in the lower part of this bed. The intraclast has deformed underlying laminated sediments (Fig. 71).

2 m scree.

0,5 m horizontally laminated sand (Sh). The laminae are dipping 11° towards 171° in the lower part and 6° towards 128° in the upper part.

Section 2

Section 2 is situated 100 m south of section 1 (Fig. 48). Section 2 starts at the level of lake Vättern (+88,5 m, Fig. 72).

3,5 m scree.

0,3 m stratified sandy diamicton (Ds). In the upper part of the bed there is a fold with the foldaxis dipping 4° towards 156° and with the axial plane dipping towards northeast. The upper limb of the fold is cut by a normal fault. Clasts are clustered near the lower limb of the fold.

0,5 m alternating laminated silt and silty diamicton (Fl, Ds). The lamination is very deformed.

0,2 m horizontally laminated and small-scale cross-laminated gravelly sand (Sh, Sr). The bed is dipping 13° towards 77°.



Fig. 72. Log of section 2 at Kaptensbo.

Section 3

Section 3 is the main section at Kaptensbo (Fig. 48). It is situated about 30 m south of section 2. The section starts at the level of lake Vättern (+88,5 m, Fig. 73).

8,8 m scree.

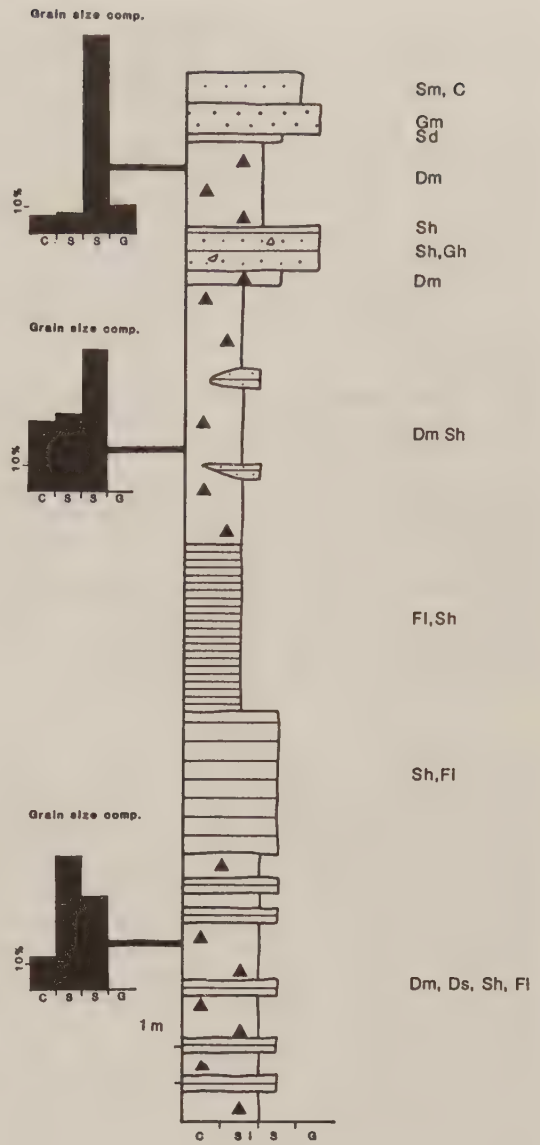


Fig. 73. Log of section 3 at Kaptensbo.

3,5 m alternated bedding of massive and stratified silty diamicton and horizontally laminated sand and silt. (Dm, Ds, Sh, Fl). Thin laminae of diamicton are found in the sand beds. In the beds there are 7 beds of diamicton. The diamicton beds are mainly massive, but a faint lamination has been observed in the upper and lower part of some units. About 1 m, 1,7 m resp. up in the horizontally laminated sand, the laminae are dipping 15° towards 253° 30° towards 320° resp.

1,9 horizontally laminated sand, silt, clay and diamicton (Sh, Fl, Ds). The diamicton laminae become less frequent upwards. Small pebbles in the unit have not deformed underlying laminae. About 10 cm up in the unit there is a small fold, with a foldaxis dipping 8° towards 310°. In the upper part of the unit there is another foldaxis dipping 20° towards 55°. This fold was probably formed when water escaped from underlying sediments. About 1,5 m up in the bed a lamina of fine sand is dipping 26° towards 17°.

2,2 m horizontally laminated clay, silt sand and diamicton (Fl, Sh, Ds). Clay dominates the unit. The diamicton beds are few and increase upwards. The horizontally laminated sand dips 16° towards 50°.

3,4 m brownish gray silty clayey diamicton (Dm). The diamicton has a heterogeneous texture with extensive lenses and beds of laminated sand, silt and clay. The diamicton is jointed with iron and manganese oxides precipitated in the fractures.

0,2 m redbrown sandy diamicton with thin laminae of silt and clay (Dm, Fl). There are many intraclasts in the unit. The clasts are clustered.

0,6 m horizontally laminated sand and gravel (Sh, Gh). There are thin contorted laminae of silt in the unit. There are many intraclasts of silt in the unit.

0,9 m brown and gray clayey silty diamicton, with many lenses of fine sand and silt (Dm, Fl). There are very few clasts bigger than coarse sand in the unit.

0,1 m very contorted laminated fine sand (Sh).

0,4 m massive sandy gravel (Gm).

0,4 m massive sand with organic material (Sm, C).

Section 4

Section 4 includes the upper part of section 3 and can be followed about 12 m towards the south. Section 4 deals more closely with the upper units at Kaptensbo, where they are better exposed. There are lateral variations in bed thickness and configuration, and the described section is a compilation of the whole section. Section 4 starts at the level of lake Vättern (+88,5 m, Fig. 74).

19 m scree.

0,8 m gray silty diamicton (Dm). The diamicton is jointed with iron- and manganese oxides precipitated in the fractures. The upper contact is loaded. There are many injection structures of silty diamicton projecting into overlying sediments (Fig. 74).

0,1 m contorted laminated fine sand and silt (Fl).

0,4 m contorted diamicton, sand and silt (Ds, Sh). The diamicton is gravely sandy with an unusual amount of clasts. Many of them are intraclasts of gravely sandy diamicton.

0,1 m rhythmically laminated silt and clay

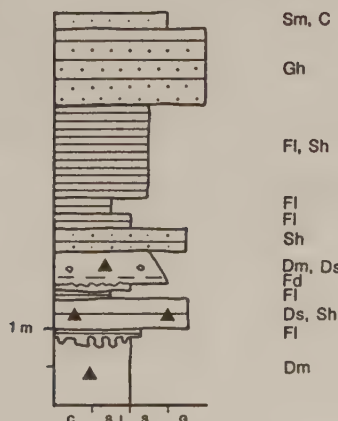


Fig. 74. Log of section 4 at Kaptensbo.

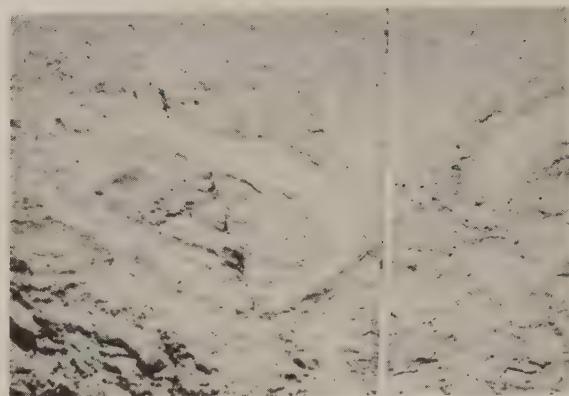


Fig. 75. Water escape structures in section 4 at Kaptensbo.

(Fl). The unit is deformed.

0,05 m contorted laminated silt (Fl). The upper contact is loaded.

0,4 m red sandy diamicton (Dm, Ds). The grain-size composition is fining upwards. In the lower part of the unit there is a faint stratification. There are many thin winding laminae of silt and clay in the unit. In the upper part of the unit there are many intraclasts of silt. The upper contact is erosive.

0,3 m faintly laminated gravely sand (Sh).

0,2 m horizontally laminated clay, silt, sand and diamicton (Fl). There are 6 clay laminae in the bed. The bed contains dropstones.

0,2 m laminated clay, silt and sand (Fl). There are about 20 laminae of clay in the unit.

1,2 m very contorted horizontally laminated silt, sand and diamicton (Fl, Sh). In the lower part of the bed there are some thin laminae of clay. There are many waterescape structures in the unit (Fig. 75).

1,0 m horizontally laminated sandy gravel (Gh). There are thin laminae of silt in the unit.

0,2 m massive sandy gravel, with organic material (Gm, C).

Section 5

Section 5 is situated about 10 m south of section 4 (Fig. 48). It starts at the level of lake Vättern (+88,5 m, Fig. 76).

9,2 m scree.

3,5 m horizontally laminated sand, silt and diamicton (Sh, Ds). Diamicton is found in three beds (0,1-0,3 m thick). Even some thin laminae occur.

Between the diamicton units there is horizontally laminated sand and silt. In the lower part of the bed there are some clay laminae. About 0,5 m up in the bed the sand laminae dip 14° towards 342°, 1,2 m up 22° towards 349° and 3 m up 26° towards 307°.

2,0 m stratified silty diamicton (Ds). There are thin laminae of sand and coarse silt in the unit. The sand and silt appears as approximately 0,1 m thick beds between thicker diamicton beds. The sand and silt content decrease upwards. About 1,5 m up in the unit there is a bed of sand and coarse silt, only slightly contorted. The laminae dips 19° towards 318°.

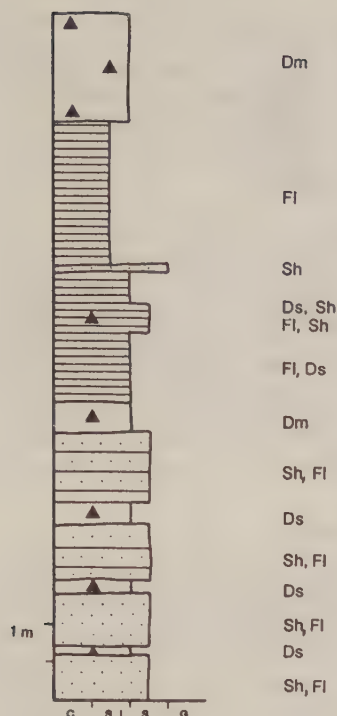


Fig. 76. Log of section 5 at Kaptensbo.

0,4 m grayish brown silty diamicton (Dm).
0,9 m folded laminated silt, clay and silty diamicton (FI, Dm). The diamicton is in the core center of the fold, with laminated silt and clay.
0,2 m folded laminated clay, silt and sand (FI, Sh). In the northern part of the section the unit is included in a fold, with a fold-axis dipping 1° towards 350° and the axial plane dipping towards the east.
0,2 m stratified diamicton and horizontally laminated sand. (Ds, Sh). In the northern part of the section the unit is included in a big fold.
0,4 m laminated clay and silt (FI). In the northern part of the section the bed is compressed and about 1 m thick. It is part of a big fold.
0,1 m very contorted laminated fine sand (Sh).
1,7 m very contorted laminated clay and silt (FI). There are thin laminae of sand and diamicton in the unit. There are some dropstones in the unit. In the middle of the unit, there is a fold with a fold-axis dipping 6° towards 350° . The axial plane is dipping towards the west.
1,4 m grayish brown silty diamicton (Dm). The diamicton is very jointed with iron- and manganese oxides precipitated in the fractures.
Scree to the top of the cliff.

Section 6

Section 6 is situated about 5 m south of section 5 (Fig. 48). The section starts at the level of lake Vättern (+88,5 m, Fig. 77).
12,5 m scree.
1,2 m grayish blue silty diamicton (Dm). There are some thin laminae of fine sand in the unit.
0,4 m contorted horizontally laminated sand,

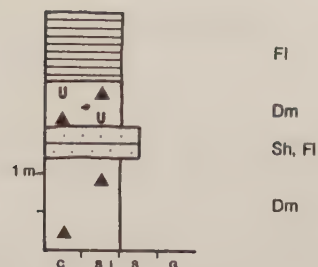


Fig. 77. Log of section 6 at Kaptensbo.

silt and diamicton (Sh, FI). Sand and silt dominates. The laminae in the unit dip 15° towards 334° .
0,6 m brownish gray silty diamicton (Dm). The unit has a massive appearance with many balls and deformed lenses of sediments (pseudo nodules).
0,9 m contorted horizontally laminated silt, sand and diamicton (FI).
Scree to the top of the cliff.

Section 7

Section 7 is situated about 15 m south of section 6 (Fig. 48). It starts at the level of lake Vättern (+88,5 m, Fig. 78).
3,0 m scree.
0,6 m laminated sand, silt and diamicton with thin laminae of clay (Sh, Sr, FI). In the lower part of the unit there are sinusoidal and type-B ripples. The laminae in the horizontally laminated sand are dipping 26° towards 206° .
4,0 m grayish blue silty diamicton (Dm). In the upper part of the bed there are some laminae of sand and silt. In the massive central part of the bed, there are lenses and balls of sand (pseudo nodules). In the central part of the section there is a big U-shaped fault structure. The northern faultplane dips 84° towards the south and strikes $70-250^\circ$, the southern faultplane dips 78° towards the south and strikes $92-272^\circ$, and in the bottom of the U the faultplane dips 80° towards the west and strikes $0-180^\circ$. (This indicates that the upper part of the section was pushed towards the west.) In the northern part of the section there are two normal and one reverse fault. The faultplane of the reversed fault dips 70° towards the

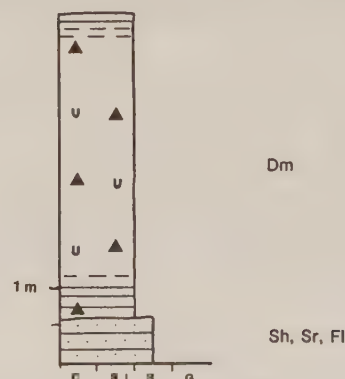


Fig. 78. Log of section 7 at Kaptensbo.

southwest and strikes $12-192^{\circ}$.

Section 8

Section 8 is situated about 5 m south of section 7 (Fig. 48). It starts at the level of lake Vättern (+88,5 m, Fig. 79).

3,5 m scree.

2 m grayish blue silty diamicton (Dm). In the lower part of the bed there are thin laminae of sand, silt and clay. The sand laminae dip 2° towards 136° . The rest of the diamicton bed is massive, with lenses and balls of sand and coarse silt (pseudo nodules). There are very few clasts in the unit, but in the middle of the it there is a boulder with a diameter of about 0,4 m. In the southern part of the section some normal faults occur. One faultplane dips 78° towards the south and strikes $98-278^{\circ}$, and another dips 86° towards the south and strikes $82-262^{\circ}$.

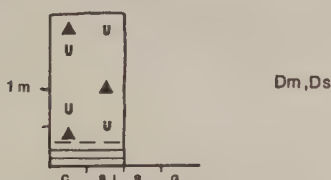


Fig. 79. Log of section 8 at Kaptensbo.

7:3:2 Discussion

At Kaptensbo, the Kaptensbo beds totally dominate the sections. The Rosenlund diamicton has not been positively recognized. The Öxnehaga diamicton is very thin and heterogeneous.

The Kaptensbo beds.

The Kaptensbo beds consist of massive and stratified beds of diamicton, horizontally laminated sand, silt and clay. The fine grained sediments and the dropstones indicate deposition in a subaquatic environment. The diamicton beds often have faint stratification in the lower and upper parts, indicating deposition by debris flows (Carter 1975, Lawson 1979). The thick massive beds of diamicton in the lower part of the cliff might have been deposited by undermelting (Gravenor et al. 1984), but there is no positive evidence of this.

The sand and coarse silt seldom display graded bedding, they are often poorly sorted and often show faint lamination, indicating deposition by high concentration turbidity currents (Middleton 1967) or modified grainflow (Lowe 1976a). Liquefied flow probably acted during the transportation of the sands and fluidized flow acted when the waterescape structures, such as pseudo nodules and the convoluted bedding, were formed.

The fine silt and clay fell out of suspension in low energy waters.

The folding and faulting in the sections indicate tectonic deformation. The U-shaped fault structure in section 7 indicates that

the upper part of the section moved towards west. For the same reasons as in Vilhelmsro, buried ice between the site and the bedrock cliff 500 m to the west, was not likely. This indicates that the Kaptensbo beds were displaced and deformed by a glaciotectionic pressure from the east.

The Rosenlund diamicton.

The Rosenlund diamicton has not been positively recognized at Kaptensbo. In the upper part of sections 3 and 4 there is a bed, looking vaguely like the Rosenlund diamicton (the jointing), but the texture, rock fragment composition and sediment structures are somewhat different from the Rosenlund diamicton in the vicinity.

The Öxnehaga diamicton

In the upper part of sections 3 and 4 there are thin beds of red sandy diamicton. The beds are often stratified. The texture and rock fragment composition do not exclude that these beds are part of the Öxnehaga diamicton. The diamicton beds are debris flow sediment, deposited in a subaquatic environment.

According to Svantesson (1985), there is a glaciofluvial deposit close to the site. It is partly covered by diamicton (Svantesson 1985, Nilsson 1939). It is likely, that the uppermost laminated sand and gravel is part of this deposit.

7:3:3 Conclusions

The Kaptensbo beds were deposited in a glaciolacustrine environment by sediment gravity flows. The Rosenlund diamicton has not been distinguished. The Öxnehaga diamicton was deposited in a glaciolacustrine environment by debris flows.

The sediments were deformed by a glaciotectionic pressure from an eastern sector.

7:4 The excavation of Sanda.

At the Sanda school about 1,1 km south of the outlet of the river Huskvarnaån there has been an excavation for a new gymnasium (Fig. 25). Two sections are described. Section 1 is situated about 50 m east of the main entrance to the school, and displays the upper part of the stratigraphy (Fig. 80). Section 2 is situated about 75 m south of the school building. Section 2 is about 4 m high and 40 m long (Fig. 81). Three stratigraphic units are distinguished in the sections; the Rosen-

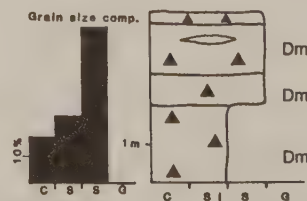


Fig. 80. Log of section 1 at Sanda.

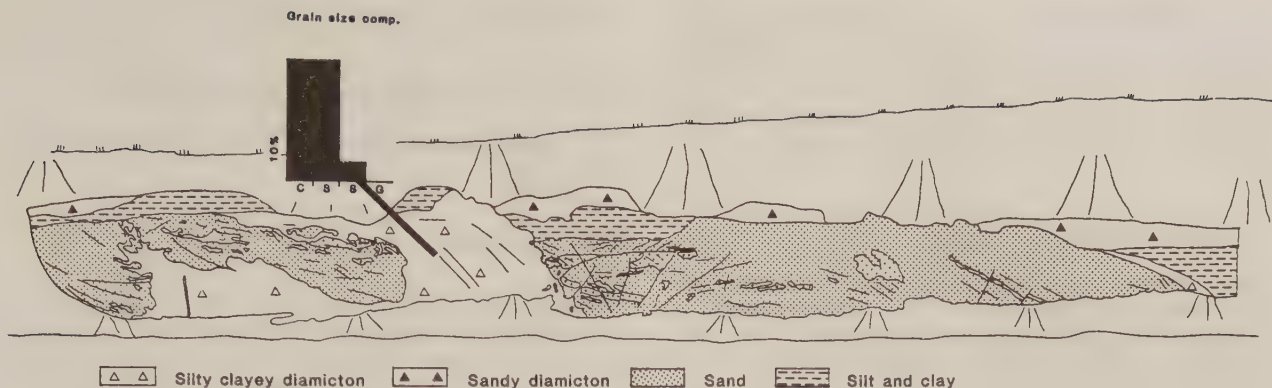


Fig. 81. Section 2 at Sanda.

lund diamicton, the Sanna beds and the Öxnehaga diamicton. The site is situated on a relatively steep slope dipping towards the north or northeast.

7:4:1 Sections

Section 1

The top of the section is situated at about +125 m. The section is described from bottom to top (Fig. 80).

2 m gray silty clayey diamicton (Dm). It is jointed in the upper part (1 m) of the bed. Downwards, the diamicton becomes more clayey. The upper contact is interbedded.

0,8 m reddish or yellowish brown sandy diamicton (Dm). In the upper part of the bed there are some thin laminae of silt and clay. Some of these laminae are possible to follow up into the overlying bed. There are very few extrabasinal clasts, but there are many intraclasts of diamicton in the bed. The clasts are well rounded. The upper contact is conformable.

1,3 m redbrown sandy diamicton (Dm). There are many lenses and laminae of clay and silt in the bed. These laminae are draped over clasts and often consist of many layers of different texture.

0,3 m massive sandy diamicton with organic material (Sm,C).

Section 2

Section 2 is situated about 75 m south of the school building. The section strikes northwest-southeast and is about 40 m long and about 4 m high. The units in the section are deformed, folded and faulted (Fig. 81). The bottom of the section is at about +125 m. The section is described from bottom to top.

0-3 m silty clayey diamicton (Dm). The diamicton is very jointed in the upper parts, but in hollows dug in the vicinity of the section the jointing declines and disappears about 1 m below the bottom of the section. The silty clay diamicton has in some places been squeezed through overlying sediments and dragged out in long subhorizontal streaks. The streaks are pointing towards the southeast (Fig. 81). (The bed is correlated with the Rosenlund diamicton.)

0-3 m of horizontally-, small-scale cross-laminated and cross laminated sand (St, Sh, Sr). In the upper part of the bed there are laminated silt and clay (F1). Most of the sediments are very deformed and structural recognition is very difficult. The bed is penetrated by a number of faults (Figs. 82 and 83) some of which are possible to follow down into the upper part of underlying diamicton.

In the upper part of this bed the sediments are spotted, yellowish brown and white. This is probably caused by some secondary process. (This bed has been correlated with the Sanna beds.)



Fig. 82. The deformed and displaced sediments in the central part of section 2 at Sanda.

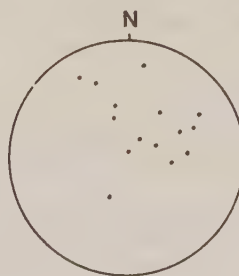


Fig. 83. The dip and directions of the foldplanes in section 2 at Sanda.

1 m of reddish gray silty diamicton (Dm). The contact to underlying sediments is grading. In the lower part of the bed the texture is similar to underlying sand, silt and clay. Further up in the bed the diamicton looks more like the normal Öxnehaga diamicton in the area.

7:4:2 Discussion

The silty clayey diamicton is correlated to the Rosenlund diamicton, the superimposing water-sorted sediments are correlated to the Sanna beds and the upper diamicton is correlated to the Öxnehaga diamicton. The stratigraphic correlation of the Rosenlund diamicton is based on the relative stratigraphic position, the grain size composition the jointing and the color. For the overlying units the stratigraphic position is the main criterium for correlation.

On top of the Rosenlund diamicton at Sanda, meltwater flowed in shallow furrows. Cross-laminated, small-scale cross-laminated and horizontally laminated sand was deposited in the meltwater channels. On top of the fluvial sediments glaciolacustrine silt and clay were horizontally deposited.

The Rosenlund diamicton and the Sanna beds were deformed. Part of the deformation can perhaps be explained by gravity movement due to density differences of the silty clayey diamicton and the overlying sand, but there are many indications of a horizontal stress from a northern sector. For instance, it is unlikely that the streaks of Rosenlund diamicton would point in a southern direction in a slope dipping towards the northeast, if only gravity forces acted on the sediments. The faults and the shear structures in the section, indicate a lateral pressure from north. The Öxnehaga diamicton has not been faulted, indicating that the deformation was formed before or during the deposition of the Öxnehaga diamicton. This is an argument in favor of subglacial origin of some parts of the Öxnehaga diamicton.

A small section, about 250 m east of section 2, displays about 4 m of sandy or gravely sandy diamicton above the Rosenlund diamicton. Clasts bigger than pebbles are very unusual and all clasts are well rounded. It is obvious that this diamicton is a reworked glaciofluvial sediment. In small sections west of Sanda the Öxnehaga diamicton is silty or clayey, reflecting underlying sediments.

The most simple way to explain the structures at Sanda is a glacier overriding the area, causing extensive deformation of already deposited sediments. Sediments were picked up and reworked by the glacier and redeposited as the Öxnehaga diamicton.

7:4:3 Conclusions

At Sanda it has not been possible to get any information about the genesis of the Rosenlund diamicton.

The Sanna beds were deposited in water eroded shallow furrows in the Rosenlund diamicton, probably in a subaquatic environment.

An overriding glacier has deformed and incorporated underlying sediments, before the Öxnehaga diamicton was deposited. This indicates that the Öxnehaga diamicton was

deposited by a glacier.

7:5 Small sections in the Rosenlund area

The positions of the sections are shown in Fig. 26.

7:5:1 Sections

Brandstation

Section 1 is an excavation for a house about 500 m southwest of the camp site at Rosenlund. The top of the section lies at about +125 m. The section is about 3 m high. The stratigraphy is described from bottom to top (Fig. 84).

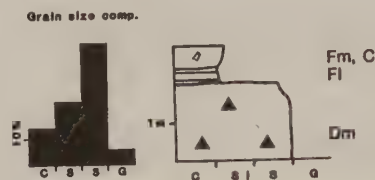


Fig. 84. Log from Brandstationen.

1,5 m red clayey sandy diamicton (Dm). The diamicton is soft and quite homogeneous. The clasts are few and usually well rounded. There is a slightly higher clast content in the upper part of the bed. Clasts crystalline rocks are often weathered. The rock fragment composition is about 76% Visingsö Group of Rocks and 24% crystalline rocks.

Two fabric analyses were made in the section. They show an almost random orientation of clast long axes. (The bed is correlated with the Öxnehaga diamicton). The contact to overlying sediments is grading.

0,4-2 m massive or rhythmically laminated silt and clay (Fm, FI). The bed is usually massive and about 0,4 m thick, but in the southernmost part of the section there is a trench in the diamicton filled with about 2 m of silt and clay. The lower part of the unit consists of rhythmically laminated silt and clay. The laminae are 1-3 mm thick and diminish upwards.

0,3 m massive clay with organic material (Fm,C).

0,6 m artificial fill.

Aristokrat

Section 2 is an excavation for a factory (Fig. 26). The top of the section lies at about +130 m. The section is about 3 m high and is described from bottom to top (Fig. 85).

1 m dark gray silty clay diamicton (Dm). There are many intraclasts of sand. Some of the intraclasts are deformed. In the diamicton there is a vertical sand filled joint, striking 52-232°. (The bed is correlated with the Rosenlund diamicton.)

0,05 m very deformed laminated sand (Sd).

1,0 m redbrown clayey silty diamicton

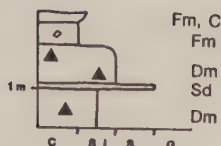


Fig. 85. Log from Aristokrat.

(Dm). There are very few clasts. Intraclasts of sand and lenses of sand and silt are common in the unit. (The unit is correlated with the Öxnehaga diamicton.)

0,7 m yellowish brown massive clay (Fm). (The bed is correlated with the Ekhangen clay.)

0,3 m massive clay with organic material (Fm, C).

Gula Sanna

The location of section 3 is found in Fig. 26. The section is a 4 m deep excavation for a small building. The top of the section lies at about +115 m. The stratigraphy is described from bottom to top (Fig. 86).

1 m dark gray silty clay diamicton (Dm). The diamicton is compact and jointed. (It is correlated with the Rosenlund diamicton.)

1 m redbrown clayey sandy diamicton (Dm).

2 m artificial fill.

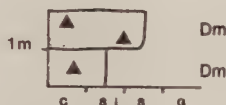


Fig. 86. Log from Gula Sanna.

7:5:2 Discussion

The silty clayey diamicton is correlated to the Rosenlund diamicton. The water-sorted sediments superimposing the Rosenlund diamicton are correlated to the Sanna beds. The redbrown, sandy diamicton is correlated to the Öxnehaga diamicton, and the massive or rhythmically laminated silt and clay is correlated to the Ekhangen clay. The stratigraphy in the area is from the bottom and up.

Rosenlund diamicton, Sanna beds, Öxnehaga diamicton and Ekhangen clay. It is obvious from the sections that these units are widespread in the area.

The fabric analyses in section 1. show an almost random orientation of clast long axes indicating that the unit was not deposited in a subglacial position. The grading contact to overlying clay indicates that the Öxnehaga diamicton was deposited in a subaquatic environment. The Ekhangen clay is usually less than 0,5 m thick and massive in the area, but in the trench in section 1 it is about 2 m thick and displays a very fine rhythmically lamination in the lower part of the bed. This indicates a distal depositional position, but the lamination is found in protected areas, indicating that higher areas were too much exposed for deposition of laminated clay.

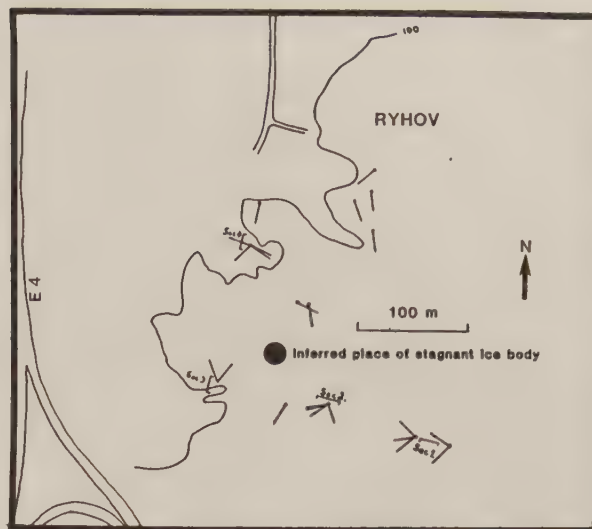


Fig. 87. Map of the Ryhov area.

7:6 Ryhov

In Ryhov, the foundation for the new Jönköping hospital has been excavated. The site and the sections are shown in Fig. 87. One big section in the southeastern part of the excavation is described, as well as small sections in the western wall, and scattered areas from the northwestern part of the excavation. At the bottom of section 1 (the SE-corner) a drilling was made by SGU in april 1981 using a new sampler for non-cohesive soils (Johansson & Söderström 1982). I visited the drilling and had the opportunity to inspect the core.

7:6:1 Sections

The localities of the sections are shown in Fig. 87. In the eastern and lower part of the excavation it has been possible to see the Rosenlund diamicton. The surface of the diamicton bed is dipping toward the west. The Rosenlund diamicton is not visible in the western part of the excavation. Upwards, the diamicton is interbedded with water-sorted sediments. The Ryhov sands superimpose the Rosenlund diamicton with an interbedded contact. The Ryhov sands consist mainly of cross-laminated and small-scale cross-laminated sand.

Section 1

Section 1 is situated in the southeastern part of the excavation Fig. 87. The drilling started about 6 m below the ground and about 0,5 m below the bottom of section 1. The drilling stopped at the bedrock or at a big boulder at about +80 m. The stratigraphy is described from bottom to top starting with the drilling (Fig. 88).

5 m laminated sand grading into rhythmically laminated fine sand, silt and clay (Sh, Fl).

13 m silty clay diamicton with few clasts (Dm).

0,5 m scree.

Start of the cleaned section.

0,6 m bluish gray silty clayey diamicton

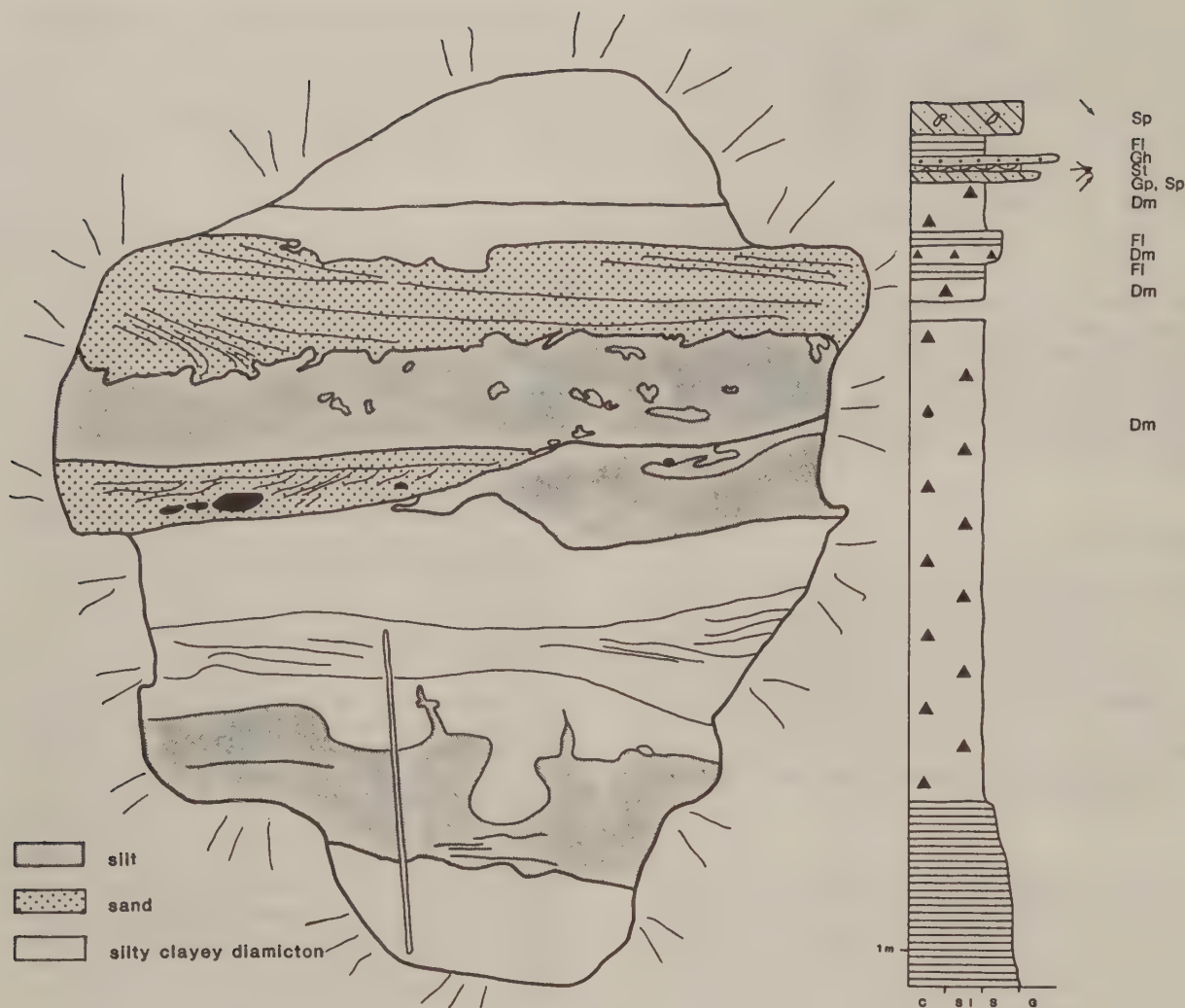


Fig. 88. Sketch and log of section 1 at Ryhov.

(Dm). The diamicton is compact and very jointed. There are no precipitations in the fractures, but some of the fractures are filled with sand. The upper contact is sharp and conformable. The rock fragment composition is 76% Visingsö Group of Rocks, 23% crystalline rocks and 1% Paleozoic limestone. 0,1-0,4 m gray laminated silt (Fl). There are many water escape structures in the unit. One ejection from this unit penetrates the overlying unit. The upper contact is sharp and conformable.

0,2-0,5 m brownish gray silty diamicton (Dm). It contains considerably more clasts than the underlying diamicton. The rock fragment composition is 62% Visingsö Group of Rocks, 37% crystalline rocks and 2% Paleozoic limestone. The upper contact is sharp and conformable. There is iron oxide precipitated in the contact.

0,3-0,4 m horizontally laminated fine sand, silt and clay (Fl). In the middle of the bed there is a 0,03 m thick lamina of silty diamicton. Small normal faults have been observed in the bed. Otherwise the lamination is undisturbed. The laminae are dipping 9° towards 105°.

1,2 m silty clayey diamicton (Dm). There are many lenses of sand, silt and clay in the

unit. The diamicton is jointed but in much smaller cubes than in the bed of the bottom of the section.

0,01-0,4 m cross-laminated sand and gravel (Gp, Sp). In the contact to underlying diamicton there is a poorly sorted sediment with cobbles in a sandy gravelly matrix. In this stratigraphic position but 10 m north of the section the foreset laminae are dipping 25° towards 43° and about 5 m further north 26° towards 123°.

0,2 m trough-bedded cross-laminated sand (St). The laminae have tangential lower contacts. The foreset laminae are dipping about 28° towards 52° and in 26° towards 81°.

0,1-0,15 m horizontally laminated sandy gravel (Gh). 0,6 m laminated silt (Fl). There are some thin laminae of diamicton. There are many dropstones and intraclasts of silt and sand and diamicton is common in the bed. The upper contact is loaded in a complicated way (Fig. 89).

0,9 m planar-bedded cross-laminated sand (Sp). In the bed there is a thin lamina of silt. There are dropstones deforming underlying laminae. Many of the dropstones are intraclasts of silty clay diamicton. The foreset laminae are dipping 28° towards 135°.



Fig. 89. Deformation structures in the upper part of section 1 at Ryhov.

In the contact to underlying laminated silt, the sand has sunk into the silt and the silt was injected into the sand (Fig. 89).
1,5 m artificial fill.

Section 2

Section 2 is situated about 150 m east of section 1 (Fig. 87). The section starts at about +98 m and is described from bottom to top (Fig. 90).



Fig. 90. Log of section 2 at Ryhov.

0,4 m trough-bedded cross-laminated sand (St). The foreset laminae are dipping 23° towards 55° .

0,2 m small-scale cross-laminated sand (Sr). There are type A ripples in the unit. The unit is dipping 18° towards 74° . The ripples indicate a current direction towards the north northeast.

0,4 m trough-bedded cross-laminated sand (St). The foreset laminae are dipping 30° towards 75° .

0,15 m small-scale cross-laminated sand (Sr). There are mainly type B ripples. The paleocurrent is towards the south or towards the east.

0,04 m sinusoidal ripples silt and fine sand (Sr).

0,15 m type-B ripples sand (Sr). Paleocurrent towards the south or towards the east.

0,04 m sinusoidal ripples sand and silt (Sr).

0,15 m type-A ripples sand grading into type-B ripples (Sr).

0,02 m sinusoidal ripples silt (Sr). There are water-escape structures in the unit.

0,06 m type-B ripples sand (Sr). Paleocurrent is towards the southeast.

0,03 m sinusoidal ripples fine sand and silt (Sr).

0,35 m horizontally laminated sand (Sh).

0,1 m sinusoidal ripples sand and fine sand (Sr). The ripples have a very low amplitude.

0,08 m type-A ripples sand (Sr). Paleocurrent is towards the northwest.

0,05 m sinusoidal ripples fine sand (Sr).

0,2 m type-B ripples sand (Sr). Paleocurrent is towards the north-west. The angle of climb is 22° in the lower and 32° in the upper part of the bed.

0,2 m sinusoidal ripples silt and fine sand (Sr). In the upper part of the bed there is a contorted lamina of clay.

1,0 m trough-bedded cross-laminated sand (St). The lower contact is tangential. There are intraclasts of clay in the bed. In the middle of the bed there is a small intraformational fossil ice-wedge. The foreset are dipping 27° towards 322° .

0,3 m massive sand with organic material (Sm,C).

Section 3

Section 3 is situated about 50 m west of section 2 in the southwestern corner of the excavation. The section starts at about +97 m and is described from bottom to top (Fig 91).

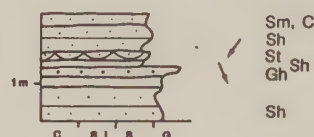


Fig. 91. Log of section 3 at Ryhov.

0,2 m horizontally laminated sand (Sh). The lamination is disturbed and faulted.

0,5 m horizontally laminated sand with thin laminae of silt (Sh).

0,2 m horizontally laminated gravely sand (Sh).

0,3 m trough-bedded cross-laminated gravely sand (St). The lower contact is tangential. The foreset laminae are dipping 15° towards 158° .

0,2 m horizontally laminated sandy gravel (Gh).

0,2 m horizontally laminated fine sand and coarse silt (Sh).

0,2 m planar-bedded cross-laminated sand (Sp). Coarse particles are accumulated at the toe of the foreset laminae. In the northern part of the section the laminae are disturbed by faulting. The undisturbed laminae are dipping 20° towards 218° .

0,2 m horizontally laminated fine sand (Sh).

0,2 m horizontally laminated gravely sand (Sh).

0,3 m horizontally laminated fine sand (Sh).

0,5 m massive sand with organic material (SM,C).

The section has been downfaulted about 1 m. A reverse fault in the northern part of the section dips 76° towards the northeast and strikes $118-298^\circ$. The sediments appear to have been deposited on a big ice body. The main body of ice was northeast of the section.

Section 4

Section 4 is situated about 100 m north of section 3 (Fig. 87). The section starts at about +97 m and is described from bottom to top (Fig. 92).



Fig. 92. Log of section 4 at Ryhov.

1,0 m planar-bedded cross-laminated sand and gravel (Sp, Gp). Pebbles, often angular, are common in the unit. Some of the laminae are poorly sorted and there is usually a diffuse boundary between the laminae. The foreset laminae are dipping 16° towards 42° .

0,4 m trough-bedded cross-laminated sand (St). The sediment is better sorted than in the underlying unit. In the lower part of the bed, the laminae are dipping 17° towards 300° and in the upper part 6° towards 109° .

0,05 m horizontally laminated gravel (Gh).

0,6 m horizontally laminated gravelly sand (Sh). There are thin laminae of fine sand in the upper part of the unit. In the middle of the unit the laminae are dipping 4° towards 297° .

0,5 m massive sand with organic material (Sm,C).

Gross description

In the southern trench it is possible to see that the unit of silty clayey diamicton is dipping towards a western sector.

In the central part of the excavation the gross stratigraphy is more than 4 m of planar-bedded cross-laminated sand and fine sand (Sp), superimposed by 1-2 m horizontally and small-scale cross-laminated sand. Measurement of the paleocurrent direction were made at several places and is shown in Fig. 87.

7:6:2 Discussion

The drilling below section 1 indicates an approximately 5 m thick sequence of glaciolacustrine sediments above the bedrock. The sequence is fining upwards. The unit might be correlated with the Kaptensbo beds. This unit is superimposed by about 16 m of bluish gray silty clayey diamicton. In the upper part of the unit there are successively more beds of water-sorted silt with dropstones. The unit is correlated with the Rosenlund diamicton, the stratigraphic position, the similar rock fragment composition, structures and texture confirm this. The whole bed is dipping towards west. This diamicton has not been found in the many drilling made between Rocksjön and Munksjön. Some of the drilling are more than 50 m deep, which is explained by the dip of the bed. On top of the Rosenlund diamicton there is planar-bedded cross-laminated sand, superim-

posed by trough-bedded cross-laminated, small-scale cross-laminated and horizontally laminated sand, and gravel. The unit is correlated with the Ryhov sand, because of the geographical position and the paleocurrent towards a northern sector. The unit displays collapse structures indicating parts of the bed were deposited on a big ice body, which displaced the sediments when it melted. The inferred position of the ice body is shown in Fig. 87. In the western part of the area there is an ice-contact slope. In the southern and southeastern part of the site the Ryhov sands is 2-3 m thick, with trough-bedded cross-lamination and small-scale cross-lamination as dominating structures. In the northern part of the excavation there is a set at least 4 m of planar-bedded cross-laminated sand and fine sand, superimposed by 1-2 m trough-bedded cross-laminated, small-scale cross-laminated or horizontally laminated sand. The laminae in the planar-bedded cross-laminated sands dip about 15° to the horizontal, which is normal in a sand delta foreset.

7:6:3 Conclusion

The stratigraphy from the drilling indicates a glaciolacustrine environment (Kaptensbo beds) passing into a subglacial environment (Rosenlund diamicton). Section 1 indicates a glacier retreating in a glaciolacustrine environment (upper part of Rosenlund diamicton). The planar-bedded cross-laminated sand is the foreset bed in a sand delta. The upper part of the Ryhov sands is the topset bed of a delta deposited in a subaerial environment or in very shallow water. This means that the waterlevel dropped from +220 m in the ice-dammed lake, to about +100 m (the top of the Ryhov sands) which is the level of the Baltic ice lake, according to Norrman (1964). During the deposition of the Ryhov sand buried ice bodies melted (Svantesson 1985). The Ryhov sand indicates a paleocurrent direction towards the north, which in turns indicates an outlet of the water either eastwards to the Baltic glacial lake, or westwards to the north of Billingen (Björck & Digerfeldt 1984).

7:7 Tokarp

7:7:1 Section

About 500 m southwest of Munksjön (Fig. 25) an approximately 4 m deep excavation for a house foundation. The section starts at about +122 m and is described from bottom to top. The section is shown in Fig. 94. In the eastern part of the section there is a normal fault, with a displacement of about 0,5 m.

0,5 m bluish gray laminated silt, with many dropstones (Fl). A thin sandlens is found in the middle of the unit. The unit is jointed with iron and manganese oxides precipitated in the fractures. The upper contact is interbedded with subhorizontal wedges of overlying diamicton projecting down into the laminated silt.

0,3-1,0 m grayish brown silty clayey diamicton (Dm). The diamicton is compact with an unusual amount of clasts. In the lower part of the bed there are some lenses of a more

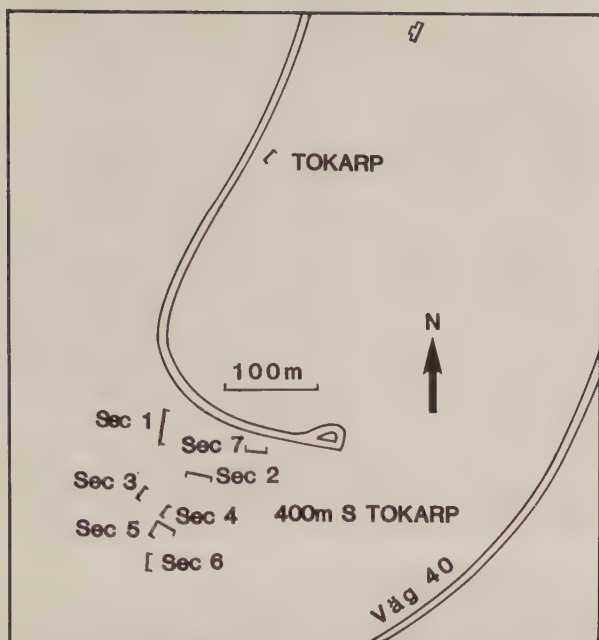


Fig. 93. Map of the Tokarp area.

sandy type of diamicton. The rock fragment composition is about 90% of Visingsö Group of Rocks and 10% crystalline rocks.

0-0,3 m contorted horizontally and small-scale cross-laminated sand and silt (Sh, Sr). In the middle of the bed there is a sub-horizontal long thin wedge of silty clayey diamicton coming from the underlying bed and almost dividing the bed in two.

0,7 m very contorted laminated silt and clay with many dropstones (Fl). There are also some laminae of silty clayey diamicton. In less contorted parts, a rhythmic lamination is visible.

0,1 m reddish brown laminated sandy diamicton, with dropstones (Ds).

0,2 m horizontally laminated poorly sorted sand and silt (Sh).

0,3 m reddish brown sandy diamicton, with many dropstones (Ds). The different laminae

often display different grain-size composition. The rock fragment content is about 70% Visingsö group of Rocks and 30% crystalline rocks.

0,4 m horizontally laminated clay, silt, sand and diamicton (Fl). There are 14 clay laminae in the bed.

0,5 m yellowish brown faintly laminated silt with 5 thin laminae of clay (Fl).

0,3 m massive fine sand with scattered pebbles (Sm).

There are indications of human influence in the bed.

0,3 m massive sand with organic material (Sm,C).

In the upper part of the section bed wedges can be found. The lamination around the wedges is sharply cut, and shows no deformation or displacement. The wedges are filled with greenish gray clay and are possible to follow down to the uppermost diamicton bed, about 1,5 m below the ground.

There are two normal faults visible in the section. The displacement is about 0,5 m and all stratigraphic units, except the uppermost massive fine sand have been displaced. The northernmost faultplane is dipping 60° towards southeast and is striking $42-222^\circ$.

7:7:2 Discussion

In the lower part of the section there is laminated silt with many dropstones deposited in a glaciolacustrine environment. It is superimposed by a bed of silty clayey diamicton. The complex contact between the silt and overlying diamicton might be due to shear stresses. The shearing could have been formed by the sliding of an overlying bed or by the shear of an overriding grounding glacier. The described contact could also have been formed by the extension of the unit by melting of buried ice, for instance.

The diamicton bed could have been deposited by sediment gravity flows, by undermelting of a floating glacier or by a grounding glacier. The diamicton is either a lodgement till or a deformed sediment.

The overlying sediment displays stratification. The clay laminae indicate deposition in a subaquatic environment. The

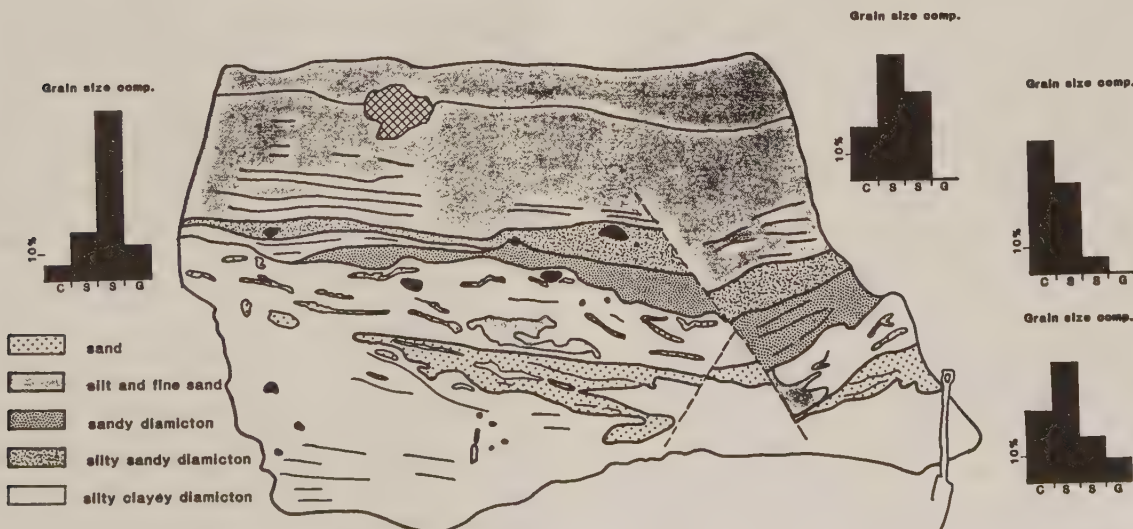


Fig. 94. The section at Tokarp.

stratified diamicton beds in the upper part of the section have a heterogeneous grain size composition and a different rock fragment composition, compared with the underlying silty clayey diamicton. These properties are expected from sediment gravity flow deposits. The rock fragment composition in the stratified diamicton indicates another source of material compared with the underlying diamicton. This new material could have been brought either from the valley slopes, by sediment gravity flows or by a new glacier in the Vättern basin. The thin beds and the heterogeneous composition favors the interpretation of deposition by sediment gravity flow. The texture and structures indicate deposition by debris flow or density modified grain flow (Lowe 1976b).

The clay in the section was deposited from suspension. The massive bed of fine sand, with scattered pebbles was probably deposited by subaerial sediment flows in postglacial time.

The normal faults, cutting most of the section, were probably formed when buried or supporting ice melted. The faults in the section indicate, that the area was not totally deglaciated between the deposition of the silty clayey diamicton and overlying sediments. The structures in the overlying sediments favor the interpretation that the upper diamicton units were deposited by debris flows from the slope west of the site. But it is also possible that a big ice body was buried in the sediments in the valley. When the ice melts debris flows are expected. It was not incorporated when a new glacier overrode the area. This ice body did not melt until the area was deglaciated. The site was probably also above the level of the lake.

The sediment gravity flows could have come either from the valley slopes in the area or directly from a glacier. The rock fragment composition in the silty clayey diamicton is different from that of the valley slope west of the site. This indicates deposition from a glacier, but sediment gravity flows from the glacier surface, standing in very deep water is not likely. The contact between the laminated silt and the diamicton is not expected from sediment gravity flows of this grain-size composition (Nemec et al. 1980). A sediment gravity flow with texture and structures of the silty clayey diamicton is a debris flow (Nemec et al. 1980, Wright & Anderson 1982, Kurtz & Anderson 1979, Carter 1975) and debris flows do not usually erode or deform underlying sediments.

Undermelting from a floating glacier or ice shelf is a possible depositional process for the diamicton bed. The change from laminated silt with dropstones, only reflects a change in depth of the watercolumn between the sole of the glacier and the bottom, which is related to the water depth of the Vättern basin (which is believed to have been constant when the basin is occupied by a glacier) and the thickness of the glacier.

The diamicton can also be a lodgement till deposited at the sole of a grounding glacier. An argument against this is that there ought to be many more deformations in the underlying laminated silt (Boulton & Jones 1979).

The contact between the glaciolacustrine silt and the diamicton is not of the type expected from a sediment successively more deformed upwards. This indicates that the silty clayey diamicton is not a deformed sediment.

The clay filled wedges in the upper part of the unit is probably of secondary origin.

7:7:3 Conclusions

All sediments in the site were deposited close to an ice body. All sediments were deposited in a glaciolacustrine environment, except perhaps the lower silty clayey diamicton, which might have been deposited by a temporarily grounded glacier. This diamicton bed is correlated with the Rosenlund diamicton, because of the stratigraphic position, similar rock fragment composition and texture. The unit is most likely an undermelt diamicton (Gravenor et al. 1984).

The upper redbrown sandy diamicton units might be part of the Öxnehaga diamicton.

The upper laminated silt and clay is probably part of the Ekshagen clay.

7:8 400 m south of Tokarp

About 400 m south of Tokarp, an area of approximately 200X70 m was excavated (Fig. 93). Several units are visible, but in the sections no more than two units are ever found on top of each other (Fig. 95).

Gross description

The gross stratigraphy at the site is from bottom to top: bluish gray silty clayey diamicton. The diamicton is jointed and contains very few clasts. The unit can perhaps be correlated with the Rosenlund diamicton.

The Rosenlund diamicton is superimposed by a redbrown sandy diamicton, with sometimes big and angular clasts. There are many often contorted laminae of sand silt and clay in the unit. The bed is at the most, 3 m thick. This unit can perhaps be correlated with the Öxnehaga diamicton. The Öxnehaga diamicton is superimposed by an up to 4 m thick bed of rhythmically laminated silt and clay, with some laminae of sand. In one spot, small-scale cross-lamination was observed. The unit can perhaps be correlated with the Ekshagen clay.

Laterally and probably superimposed on the Ekshagen clay there is a unit of cross-laminated and horizontally laminated sand and coarse silt. The bed consists of about 2,5 m planar-bedded cross-laminated sand and at least 0,5 m horizontally laminated sand and silt. Water-escape structures are often found in the bed. The cross-laminated sand indicates a paleocurrent towards the north. The unit can probably be correlated with the Ryhov sand.

Seven sections are described and their positions are shown in Fig. 95.

7:8:1 Sections

Section 1

Section 1 is situated in the northern part of the excavations (Fig. 95). The section is about 30 m long and more than 4 m high. The section starts at about +130 m.

The section consists of rhythmically laminated silt and clay with thin laminae of

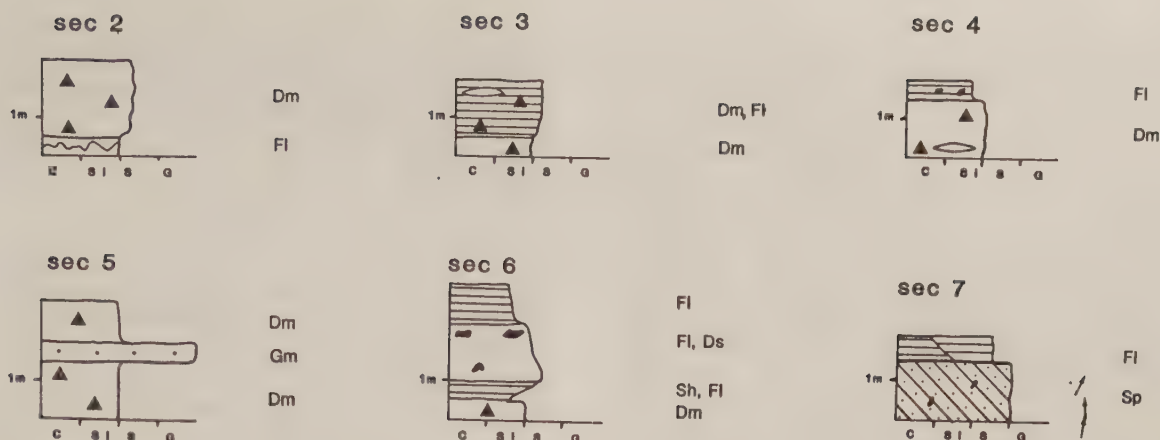


Fig. 95. Log of section 2-7 400m S. Tokarp.

sand (Fl). One sand bed displays small-scale cross-lamination. Silt dominates the section. The individual silt and very fine sand units are up to 0,3 m thick and often displays normal grading. The thick silt units often show a faint lamination.

Laminated clay units more than 0,1 m thick have also been observed. Normally, the clay laminae are about 0,01 m thick, but much thinner (less than 1 mm) clay laminae, interbedded by silt are common. There are more than 100 clay laminae in the bed. The clay is often deformed.

There are many faults in the section. All faults, but one, are normal and all of them have a northwest-southeast strike and usually dip towards the northeast.

Section 2

Section 2 is situated in the central part of the excavation (Fig. 93). The section is about 3 m high and 12 m long and starts at about +130 m. This section is shown in Fig. 95. In the central part of the section, a sandy clayey diamictite grades into the glaciolacustrine clay. In the eastern part of the section there is a trench in the diamictite in which fluvial sediments were deposited. These sediments display deformation structures throughout the bed, but they diminish upwards. In the western part of the section contorted laminated sediments were found below the massive diamictite.

The total stratigraphy in the section is described from bottom to top.

0-0,8 m contorted laminated silt and clay (Fl). Balls of sand were found in the bed.

0-2,5 m redbrown silty clay diamictite (Dm). There are very few clasts in the unit. The rock fragment composition is about 75% Visingsö Group of Rocks and 25% crystalline rocks. In the eastern part of the section there is a trench filled with laminated sand, silt and clay in a fining upwards sequence. In the middle of this sequence there is a unit of deformed poorly sorted gravel or gravely diamictite. In the top of the bed there is laminated clay. The sequence is very deformed and the laminae in the lower part of the bed stand vertical. The deformation diminishes upwards. There are no signs of erosion in the contact between the diamictite and the sorted sediments.

There are collapse structures in the upper part of the bed indicating that this sequence was deposited on a slowly melting ice body. It is not possible to say if the sand is a proximal part of the Ekshagen clay or a distal part of the Ryhov sands.

Section 3

Section 3 is situated about 50 m southwest of section 2 (Fig. 93). The section starts at about +134 m and is described from bottom to top (Fig. 95).

0,5 m grayish brown silty clay diamictite (Dm). It has a very high clay content. The diamictite is very compact and is jointed with iron and manganese oxides precipitated in the fractures. The upper contact is grading.

1,5 m redbrown silty clay diamictite with many lenses of sand, silt and clay (Dm). The laminae are contorted due to shear stresses and water escape structures. In the lower part of the bed the laminae dip steeply.

Section 4

Section 4 is situated about 10 m southeast of section 3 (Fig. 93). The section starts at about +132 m and is described from bottom to top (Fig. 95).

1,5 m grayish brown silty clayey diamictite (Dm). The diamictite has a higher content in the upper part of the bed and is more homogeneous in the lower part. In the lower part of the bed there are many lenses of sand and silt. The diamictite is jointed, with iron and manganese oxides precipitated in the fractures. The fractures are subvertical and subhorizontal. The strike and dip of some subvertical joints are shown in Fig. 96. There is a grading contact to overlying sediments.

0,5 m faintly laminated silt and clay with many dropstones (Fl). The clast content decreases upwards. The sediment is very deformed.

Section 5

Section 5 is situated 20 m south of section 4 (Fig. 93). The section starts at about +131 m

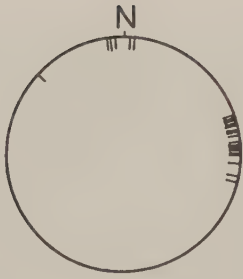


Fig. 96. The strike of subvertical joints in section 400 m S. of Tokarp.

and is described from bottom to top (Fig. 95). The section is 3 m high and there are two walls at right angles. The east-west wall is about 10 m long and the north-south wall is also about 10 m long.

0-2,5 m brownish gray silty clayey diamicton (Dm). The diamicton is jointed with iron and manganese oxides precipitated in the fractures. The contact to overlying sediment is sharp and conformable.

0-0,5 m Poorly sorted pebbly gravel with high silt and sand content (Gm). The clasts are matrix supported in most of the bed but in one spot the clasts are in contact with each other. The bed is displaced. The upper contact is sharp and conformable.

0-2,5 m redbrown silty clay diamicton (Dm).

Comments: The gravel bed in the middle of the section was probably displaced either by a diapiric uprise of the diamicton in the central part of the section, or the periphery of the gravel unit has sunk. The unit is a glaciofluvial deposit, aggraded by a powerful stream, with a very short duration. It is

likely that the gravel bed is a debris flow or a modified grain flow (Lowe 1976 a) deposited by "freezing" (Middleton 1967, Carter 1975, Lewis et al 1980, Nemec et al 1980). The geometry of the bed and the texture indicate that the bed was deposited by a debris flow.

Section 6

Section 6 is situated about 10 m south of section 5 (Fig. 93). The section is shown in Figs. 95 and 97. The section starts at about +131 m and is described from bottom to top. The section is about 5 m long and 2,5 m high. **0-0,4 m grayish brown silty clay diamicton (Dm).**

0-0,4 m very contorted laminated sand, silt and clay (Sh, Fl). The unit is coarsening upwards. There are many dropstones in the unit and the frequency is increasing upwards. The upper contact is grading.

1,2-1,6 m faintly laminated sand, silt, clay and diamicton (Fl, Ds). The diamicton content increases upwards. In the lower part of the unit there is a lens of muddy gravel. There are many dropstones in the unit. The frequency and size of the dropstones increase upwards. In the top of the unit there are many angular boulders of sandstone and there is very little deformation below these.

1,0 m contorted laminated silt and clay (Fl). In the southern part of the bed there is a lens of muddy gravel. There are some dropstones in the lower part of the bed.

Section 7

Section 7 is situated about 50 m east of section 1 (Fig. 93). The section starts at about +130 m and is described from bottom to top



Fig. 97. Section 6 400m S. of Tokarp.

(Fig. 95).

1,8 m planar-bedded cross-laminated sand with some gravel particles (Sp). There are intraclasts of clay and silty clay diamicton in the bed. There are many normal faults.

One of the faultplanes dips 68° towards the southeast and strikes $60-240^{\circ}$, another dip 70° towards the northwest and strikes $50-230^{\circ}$ and yet another dips 68° towards the southwest and strikes $130-310^{\circ}$. The foreset laminae dip 28° towards 5° , 24° towards 356° and 31° towards 25° . The upper contact is erosive and discordant.

0,7 m horizontally laminated silt with thin laminae of sand (Fl). The unit is faulted and one faultplane dips 21° towards 34° . There are many flame structures in the unit. The shape of these structures indicates that the unit was horizontally deposited.

7:8:2 Discussion

In the lower part of the excavation there is a grayish brown silty clay diamicton. This diamicton has only been found in small sections. The diamicton looks like the Rosenlund diamicton but it is not exposed enough to make a sure identification. The diamicton is jointed with iron and manganese oxides precipitated in the fractures. The strike of some of the fractures from section 3 is shown in Fig. 96. The strike and dip of the joints indicate deformation by a pressure from the north or from a northern sector.

The superimposed, very deformed laminated gravel, sand, silt and clay, might be part of the Sanna beds. The dropstones and clay laminae indicate deposition in a glacier lake. The matrix supported muddy gravel bed in section 5, is probably deposited by "freezing" of a debris flow coming down the slope west of the site. The laminated sediments grade into overlying reddish brown silty clayey diamicton. This unit can perhaps be correlated with the Öxnehaga diamicton. In the middle of the unit, the diamicton has a rather homogeneous texture, but otherwise it is heterogeneous with many lenses and laminae of gravel, sand, silt and clay. Dropstones deforming underlying laminae are common in the bed. In section 6 many angular boulders of white sandstone lie in the same level as the most homogeneous part of the diamicton unit (Fig. 97). There are no or very small deformations of underlying laminae. These boulders were perhaps not dropped from icebergs, lake ice, a floating glacier or an iceshelf. If they were not dropped, the boulders are deposited by a grounding glacier. There is a bed of laminated silt and clay, with dropstones deposited in a glaciolacustrine environment, just above the horizon with the boulders, suggesting a short period of a grounding glacier. Bigger clasts are otherwise very sparse in the diamicton. The clast content in other sections usually decreases upwards and the diamicton is grading into massive clay or laminated silt and clay.

From the deformation in section 2 it is evident that the upper diamicton unit was deposited on, or supported by ice, or glaciotectionally displaced. The rock fragment composition of the upper diamicton is about 78% Visingsö Group of Rocks and 22% crystalline rocks, which is a higher content of sedimentary rocks than the Öxnehaga

diamicton usually has.

The upper diamicton unit is grading, with an increasing dropstone content from underlying laminated sand, silt and clay, deposited in a glaciolacustrine environment, into an almost homogeneous diamicton, which grades into a water deposited clay. The easiest way to interpret this sequence is: the lower unit is deposited in a glaciolacustrine environment, which was followed by a short period of a grounding glacier, which replaced sediments deposited in a glaciolacustrine environment. Over the upper diamicton there is either massive clay or horizontally laminated clay, silt and sand. In the topographic heights this consists of about 1 m of massive clay, but in the depressions this unit consists of rhythmically laminated fine sand, silt and clay, with some thin laminae of medium sand. Normally graded, very fine sand and silt is common in the bed. Dropstones have not been found in section 1 (which is 35 m long and 4 m high) where the rhythmically laminated sediments are exposed.

The high content of silt and sand in this unit indicates a high rate of sedimentation. This is probably because the area (the section 1) is close to the sediment source, a glaciofluvial conduit or a stream carrying material of glacial origin. This is possible but not likely on the bottom of a 100 m deep lake. The lack of dropstones might suggest that the sediments have been deposited in a basin which was not deep enough to let in icebergs. This favors deposition of the rhythmically laminated sediments in a shallow lake near the source of material. Most probably this unit is part of the Ekshagen clay.

The unit of planar-bedded cross-laminated sand and horizontally laminated silt and sand was most likely superimposing the Ekshagen clay. The planar-bedded cross-laminated sand displays a paleocurrent towards the north, which is consistent with the Ryhov sand. Over the cross-laminated sand, with an erosional and discordant contact, there is a bed of silt and fine sand. The waterescape structures in the bed indicate that the bed was horizontally deposited. This unit is now dipping 21° towards 34° . There are some faults in the unit, but the displacement is not big enough to alter the interpretation of the cross-laminated sand being a foreset.

The faulting in section 1 and 7 is probably caused by release of an ice support or melting of buried ice.

7:8:3 Conclusions

The sparse information about the lowest diamicton unit gives little information of its genesis. The stratigraphic position, the geographical position, the rock fragment composition, the structures and the texture suggests the unit can be correlated with the Rosenlund diamicton.

The overlying sediments, which perhaps can be correlated with the Sanna beds, were deposited in a glaciolacustrine environment. The bed of muddy gravel, in section 5, is a sediment gravity flow deposit. These glaciolacustrine sediments grade into the upper diamicton. The lower part of the upper diamicton was deposited by sediment gravity flows and material dropped from floating ice in a glaciolacustrine environment. In section 5, there are some indications that the upper

part of the diamicton is deposited in a sub-glacial environment. The diamicton grades into a unit of clay, which perhaps can be correlated with the Ekshagen clay. The clay is probably deposited in shallow water, with a sediment supply from the south. The rhythmically laminated sediment in section 1 is perhaps the bottomset bed of a delta.

The planar-bedded cross-laminated sand in section 7 is perhaps the foreset bed of a delta with a paleocurrent towards the north. The overlying, more fine grained sediments might indicate that there might have been a shift in the sediment supply channel or a decreasing of the flow.

The deformation structures in the lower part of the stratigraphy could be of glaciotectionic origin due to the grounding of an advancing glacier, but gravity movement due to density differences (including fluidized flow or liquified flow) and sliding due to release of supporting ice could also have formed these structures. The faulting in the upper part of the stratigraphy was most likely caused by melting of buried ice or release of supporting ice.

7:9 Gripen

In a block called Gripen between Smålandsgatan and Barnarpsgratan in the Väster, in center of Jönköping, trenches have been excavated (Fig. 25). The trenches are trending 110-290°, are about 3 m deep and about 30 m long. The trenches are numbered from north to south. One section from each trench is described but if there are big lateral differences more than one section is described. 20 paleocurrent analyses were made from the maximum dip of planar-bedded cross-laminated and trough-bedded cross-laminated gravel and sand (Fig. 98).

An approximate paleocurrent is also possible to obtain from current ripples. The sections starts at about +92 m and are described from bottom to top.

7:9:1 Sections

Section 1 is located in the central part of trench 1 (Fig. 98).

0,2 m trough-bedded cross-laminated sand with some gravel particles (St).

0,15 m type-A ripples sand (Sr).

0,2 m type-B ripples sand grading into

sinusoidal ripples silt and clay (Sr, Fl).

0,01 m draped laminated clay (Fl).

0,4 m type-B ripples fine sand grading into sinusoidal ripples silt (Sr, Fl).

0,6 m horizontally laminated fine sand with thin laminae of silt (Sh, Fl).

0,2 m horizontally laminated sand (Sh).

0,1 m horizontally laminated fine sand and silt (Sh, Fl).

0,5 m faintly laminated sand and gravel (Sh, Gh).

0,4 m artificial fill.

Comment: Except for the uppermost bed the section is a fining upwards sequence.

Section 2

Section 2 is situated in the western part of trench 1 (Fig. 98).

0,4 m trough-bedded cross-laminated sand (St). The foreset laminae are dipping 17° towards 223°.

0,1 m massive silt (Fm).

0,2 m trough-bedded cross-laminated gravelly sand (St). The foreset laminae are dipping 10° towards 331°.

0,1 m type-A ripples sand (Sr).

1,0 m artificial fill.

Comments: In the eastern part of trench 1 there is planar-bedded cross-laminated sand (Sp). About 1,5 m above the trench bottom the foreset laminae are dipping 8° towards 286° and at the same level further towards the east 28° towards 326°.

Section 3

Section 3 is situated in the eastern part of trench 2, which is situated about 10 m south of trench 1. (Fig. 98).

1 m planar-bedded cross-laminated sand (Sp). The foreset laminae are dipping 22° towards 332°.

1,3 m artificial fill.

Section 4

Section 4 is situated in the western part of trench 1 (Fig. 98).

0,2 m type-A ripples sand (Sr).

0,4 m sinusoidal ripples sand and fine sand (Sr).

0,2 m sinusoidal ripples fine sand and silt (Sr).

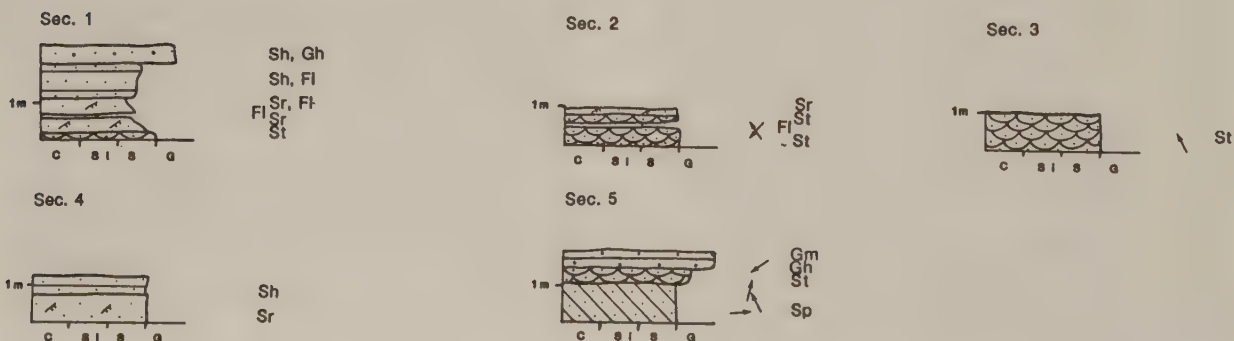


Fig. 98. Log of section 1-5 at Gripen.

0,1 m type-A ripples sand (Sr).
 0,2 m horizontally laminated fine sand, with thin laminae of silt (Sh).
 0,3 m horizontally laminated sand (Sh).
 0,5 m artificial fill.

Comments: In the central part of the trench, between sections 3 and 4, there is planar-bedded cross-laminated sand. The foreset laminae are dipping 12° towards 25° .

Trench 3 is situated about 15 m south of trench 1. Most of the trench is excavated in artificial fill. In the lower part of the trench there is planar-bedded cross-laminated pebbly gravelly sand (Sp). The clasts usually dip less than the laminae in the bed. In the eastern part of the trench the foreset laminae are dipping 30° towards 324° , in the middle of the trench 31° towards 315° and in the western part 28° towards 326° .

Trench 4 is situated about 25 m south of trench 1. In the trench there is planar-bedded cross-laminated sand and gravelly sand (Sp). The foreset laminae are dipping 12° towards 352° . The cross-laminated sand is superimposed by 1,5 m of artificial fill.

Section 5

Section 5 is situated in the western part of trench 5, which is situated about 35 m south of trench 1 (Fig. 98).

0,5 m planar-bedded cross-laminated gravelly sand with some pebbles (Sp). The foreset



Fig. 99. A fossil icewedge in section 5 at Gripen.

laminae dip 22° towards 224° . The bed is grading into overlying sediments.

1,0 m trough-bedded cross-laminated sand and fine sand (St).

In the lower part of the unit the foreset laminae dipping 10° towards 87° and in the upper part 12° towards 334° .

0,3-0,5 m trough-bedded cross-laminated gravelly sand (St). In the lower part of the unit the foreset laminae dip 24° towards 11° and in the upper part 13° towards 236° .

0,2 m horizontally laminated gravel (Gh).

0,1 m pebbly gravel (Gm).

0,3 m artificial fill.

Comments: The top of the section is levelled to +94,11 m. In the section there is an approximately 0,8 m long fossil ice-wedge. It starts about 0,6 m below the top of the section in a unit of trough-bedded cross-laminated gravelly sand. The wedge is filled with massive gravelly sand. In the upper wider part of the wedge there are deformation structures in the surrounding trough-bedded cross-laminated sand (Fig. 99).

In the central part of the trench about 2 m below the ground there is a unit of planar-bedded cross-laminated gravelly sand (Sp). The foreset laminae are dipping 31° towards 275° .

Trench 6 is situated about 20 m south of trench 5. In the trench there is 1,4 m of trough-bedded cross-laminated gravelly sand (St) with some pebbles. In the lower part of the unit the foreset laminae dip 3° towards 252° and in the middle of the unit 38° towards 331° .

The trough-bedded cross-laminated sand is superimposed by 1 m of artificial fill.

In the southern part of the excavated area there is a small excavation displaying planar- and trough-bedded cross-laminated sand and gravel. About 1,5 m below the ground the foreset laminae are dipping 13° towards 309° and at the same level, 5 m to the west, 31° towards 337° .

7:9:2 Discussion

In the lower part of the sections there is often planar-bedded cross-laminated gravelly sand (Sp). The foreset laminae are dipping towards the north indicating a paleocurrent towards the north.

The position of the unit and the overlying sediments indicate that the planar-bedded cross-laminated gravelly sand might be a foreset bed in a delta.

The overlying trough-bedded cross-laminated sand is the deposit of migrating dunes in a channel of flowing water. The dunes show a consistent paleocurrent towards the north. The sinusoidal ripples and coherent material are deposited in low energy waters next to the main tributaries or in periods of low discharge.

The upper part of the sections often display horizontally, massive or trough-bedded cross-laminated pebbly, gravelly sand. These sediments were probably deposited in a shallow water, the unit was perhaps the topset bed of a delta.

The wedge in section 5 is interpreted as a fossil ice-wedge. The wedge was probably intraformationally formed, which would indicate subaerial conditions during the sedimentation of the upper units of the sections. This suggests that the trough-bedded cross-

laminated, horizontally or massive sand is the topset bed of a delta.

7:9:3 Conclusions

The structure in the sections indicates a north flowing river depositing a delta in a lake with a waterlevel of about +95 m. The river is probably Tabergs ån and the material was derived from the large sand deposits in the Tabergs ån valley. The erosional scars in the valley sides is evidence of that.

7:10 Jägmästaren

In the block of Jägmästaren (Fig. 25) the Väster in central Jönköping there is an approximately 6 m deep excavation for a church foundation. Three sections are described. The top of the sections is at about +100 m (Fig. 100).

7:10:1 Sections

Section 1

Section 1 is situated in the southern wall of the excavation.

4,5 m planar-bedded cross-laminated sand and gravel with some pebbles (Sp, Gp). There are often type-A and type-B ripples in the foreset laminae indicating paleocurrent opposed to the dip of the foreset laminae (regressive ripples). A set of type-B climbing ripples is also observed in the unit, with an angle of climb at about 38°. About 0,5 m up in the unit the foreset laminae are dipping 20° towards 306°, about 1,1 m up, 16° towards 47°, about 1,9 m up, 10° towards 16°, 2,3 m up 22° towards 343°, 2,8 m up, 16° towards 306°, 3,3 m up, 31° towards 334°, 4,1 m up, 27° towards 350° and 4,2 m up in the unit 22° towards 12°.

0,2 m sinusoidal ripples fine sand (Sr).

0,2 m small-scale cross-laminated fine sand (Sr).

0,3 m planar-bedded cross-laminated sand (Sp). The foreset laminae are dipping 18° towards 268°.

0,7 m massive gravely sand (Sm).

Section 2

Section 2 is situated in the northern wall of

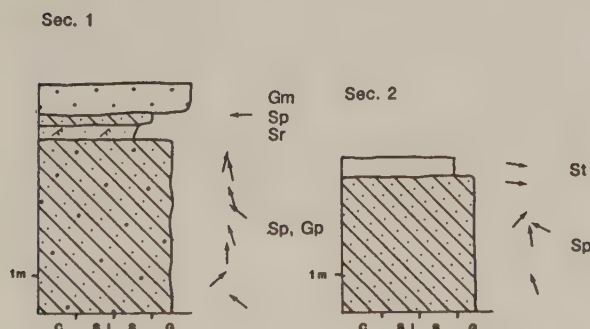


Fig. 100. Log 1-2 at Jägmästaren.

the excavation (Fig. 100).

3,5 m planar-bedded cross-laminated sand and gravel with some pebbles (Sp, Gp). About 1 m up in the unit the foreset laminae are dipping 25° towards 342°, 2,3 m up, 31° towards 353°, 2,6 m up, 24° towards 44°, 3,3 m up, 28° towards 96°. About 2,3 m up in the unit, about 10 m to the west of the section, the foreset laminae are dipping 8° towards 296°. About 2,7 m up in the unit there is a normal fault, with a displacement of about 3 cm, the faultplane is dipping 86° towards the east and is striking 42-222°.

0,5 m trough-bedded cross-laminated sand (St). The foreset laminae are dipping 18° towards 304° and about 1 m to the east, 20° towards 99°. There are many small normal faults in the unit.

0,7 m massive gravely sand (Sm).

Section 3

Section 3 is a 50 m long and 2,5 m high wall in the southernmost part of the excavation. The stratigraphy is uniform in the wall (Fig. 100).

1,8 m planar-bedded cross-laminated sand and gravel (Sp, Gp). In the south-eastern corner of the excavation, about 1 m up in the unit, the foreset laminae are dipping 20° towards 239°, at the same level, 10 m to the west, 30° towards 288°. In the central part of the section the foreset laminae are dipping 29° towards 253° approximately 1,5 m in the unit.

0,7 m massive gravely sand (Sm).

7:10:2 Discussion

The lower unit of planar-bedded cross-laminated sand in the excavation at Jägmästarn was probably a foreset bed in a delta, indicating a paleocurrent roughly towards the north. The regressive climbing ripples indicate a high rate of sedimentation and much material falling out of suspension. The upward change into trough-bedded cross-lamination indicates a deposition in a fluvial and probably a more shallow environment. This bed might have been the topset bed of the delta. The uppermost massive gravely sand is most likely the upper part of the topset bed, altered and homogenized by secondary processes. The small faults found in the excavation indicate melting of buried ice-bodies, but there are also other possibilities.

The rock fragment composition is about 44% Visingsö Group of Rock and 50% crystalline rock. This is a much lower content of sedimentary rocks than other units in the area (the Sanna beds at Rosenlund have a rock fragment composition of about 80% Visingsö Group of Rocks). This confirms the hypothesis that the sediment was derived from the south. It can be compared with the sediments from Barnarp, about 10 km to the south, which have a rock fragment content of 45-50% of Visingsö Group of Rocks.

7:10:3 Conclusions

A north flowing river has deposited a delta in a lake, with a water level of about +100 m. The material building up the delta is derived from the south, probably from the

Tabergsån valley. The paleocurrent and the geographical position indicate that the sediments can be correlated with the Ryhov sand.

7:11 Drillings in the western center of Jönköping

Many drillings for reconnaissance as well as water prospecting was carried out at the western center of Jönköping (Svantesson 1985). In the central part of this area there is about 50 m of unconsolidated sediments above the basement. The basement is white sandstone of the Visingsö Group. Here the sandstone is about 100 m thick and the surface dips to the east. In the western part of the western center of Jönköping, the unconsolidated sediments are less than 20 m thick. Most drilling logs only tell the depth of the basement, but sand and gravel have been recorded down to at least 23 m. Several other drillings record sand and gravel down to about 15 m. A hollow, filled with peat, has been found in the area. It is interpreted as a kettle hole.

7:11:1 Discussion

The drillings at Väster in the center of Jönköping confirm the observation from Gripen and Jägmästarn that the whole area consists of a large and thick sanddelta. The peat filled hollows and the faultings in the sections, indicate that ice-bodies supported or were embedded in the sediments.

7:12 Brunstorp

The section is situated about 300 m south of Brunstorp north of Huskvarna (Fig. 25). The section is an erosion scar due to leaking ground-water, in a road cut (Fig. 101). The top of the section starts at about +125 and lies at the level of the terrace of Brunstorp. The stratigraphy is described from bottom to top.

2,2 m brownish gray sandy silty diamicton (Dm). The diamicton is very compact and has one subvertical and one subhorizontal joint system. There are iron and manganese oxides precipitated in the fractures. The rock fragment composition is about 90% Visingsö Group of Rocks and 10% crystalline rocks.

0-1,5 m laminated silt, clay and diamicton

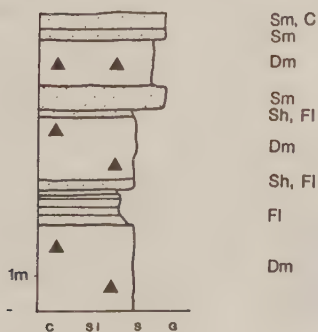


Fig. 101. Log from Brunstorp.

(Fl). The sediments are folded. In the central part of the fold there is a redbrown stratified sandy diamicton, which was probably the uppermost bed before the folding. The sandy diamicton is surrounded by light gray stratified silty diamicton and silt. There are many intraclasts of silty diamicton and sand.

0,1 m stratified silty diamicton (Ds).

0,3 m horizontally laminated sand, silt clay and silty diamicton (Sh, Fl, Ds). This unit lies conformable on top of the folded sediments. The bed is a fining upwards sequence with sand dominating in the lower part. The sequence ends with a 3 cm thick lamina of clay. In the lowermost sand lamina there is a lot of precipitated iron and manganese oxides.

1,6 m reddish gray sandy silty diamicton (Dm). There are many winding laminae of sand, silt and clay in the unit. In the unit there are many weathered clasts. In the middle of the unit sand and clay laminae are folded around a boulder. In the central parts of the fold there is a deformed lamina of diamicton. The rock fragment content is 91% Visingsö Group of Rocks and 9% crystalline rocks.

0,2 m laminated sand, silt and sandy silty diamicton (Sh, Fl, Ds). The diamicton is grayish brown.

0,6 m massive gravely sand (Sm). The sediment is poorly sorted.

1,2 m brown sandy diamicton (Dm). There are many lumps, balls and winding laminae of light gray or greenish gray, clayey sandy diamicton in the unit. In the contact to the surrounding diamicton there is often an ochra colored zone. The rock fragment composition is 88% Visingsö Group of Rocks and 12% crystalline rocks.

0,2 horizontally laminated gravely sand (Sh).
0,5 m massive gravely sand with organic material (Sm,C).

7:12:2 Discussion

The lowest unit in the section is very similar to the Rosenlund diamicton in appearance, rock composition, structures and stratigraphic position, but the texture is much coarser. The coarse grain-size composition could be due to the position of the section, which is very close to the Huskvarna faultzone (Figs. 4 and 5) and to the shore of former lakes. More beach material was incorporated in the diamicton in this area compared with the sediments derived from the central and deeper part of the Vättern basin. The superimposed laminated silt and the folded sediments were deposited in a sub-aquatic environment. Massmovements and sub-glacial shearing of a grounding glacier or ice-berg are the two processes that can form this type of fold. (The direction of the foldaxes, is approximately in the direction of the basement slope). It is possible that the diamicton laminae in the unit were deposited by subaquatic debris flows from the very steep cliff about 50 m east of the site and that the deformation is formed by drag-forces from an overriding slide or sediment gravity flow. Massmovement in the area move in a westerly direction (the direction of slope) and is not likely to have formed an isoclinal fold with a foldaxis trending approximately east west. It is not likely that debris flows from the almost ver-

tical fault wall, only 50 m apart, would stop in the middle of the slope. This suggests that the fold was formed by a grounding glacier or an iceberg. Slumps in such a steep slope would most likely develop into turbidity currents (Hampton 1975, Nemec et al. 1980). This suggests that the diamicton was deposited by undermelting of icebergs, an iceshelf or a floating glacier.

Conformably over the folded sediments there are laminated clay, silt, sand and diamicton deposited in a subaquatic environment in a successively more distal position relatively to the glacier. The folding of underlying sediment must have happened before the unit of laminated sediments was deposited. With a conformable contact the laminated sediments are superimposed by a silty clayey diamicton. The clay laminae in the bed indicate a deposition in a subaquatic environment. The clay laminae were deformed after sedimentation, perhaps due to glacier shearing. Overlying laminated silt, sand and diamicton indicate deposition in a subaquatic environment either by sediment gravity flows or undermelting. The superimposed massive gravely sand might represent a subaerial episode of fluvial deposition, but far more likely was sedimentation in subaquatic environment by sediment gravity flows or a temporary shift in the glaciofluvial drainage system. There is no evidence of subaerial deposition in the unit.

The uppermost diamicton looks like the Öxnehaga diamicton. It is brown, sandy, silty and has the characteristically light gray or greenish gray spots and winding wedges of a more clayey diamicton. The rock fragment composition, with about 88% Visingsö Group of Rocks, is much higher than what is common in the Öxnehaga diamicton. The rock fragment composition is about the same as the underlying Rosenlund diamicton. However this high content of Visingsö Group of Rocks has been found in many other beds correlated with the Öxnehaga diamicton on the eastern shore of lake Vättern.

7:12:3 Conclusions

The lowest unit in the area might be correlated with the Rosenlund diamicton, because of the stratigraphic position, geographic position, the similar texture and structures. Overlying laminated and folded sediments were deposited in a glaciolacustrine environment in rather deep water by undermelting of an iceshelf, a floating glacier or icebergs. The

floating ice-bodies sometimes grounded, deformed and perhaps folded underlying sediments. The laminated sediments are probably part of the Sanna beds, because of the stratigraphic position and the inferred paleoenvironmental interpretation. The uppermost diamicton might be correlated with the Öxnehaga diamicton, because of the stratigraphic position and the inferred paleoenvironmental interpretation.

7:13 Warpa Skans

Warpa skans is a restaurant on the eastern shore of lake Vättern. In the cliff close to the main building two sections are described (Fig. 102).

There is about 25 m between the sections. Section 1 is south of section 2 and starts about 1 m above lake Vättern. Section 2 starts about 5 m above the level of the lake. The two sections are not possible to trace in the cliff, but the closeness of the sections and the stratigraphy indicate that section 2, with perhaps a short overlap, is a continuation of section 1.

7:13:1 Sections

Section 1 starts about 1 m above the level of lake Vättern and is described from bottom to top (Fig. 102).

1,0 m gray silty clayey diamicton (Dm). Inclined wedges of diamicton project up into overlying sediments. The upper contact is erosive.

1,5-2,0 m horizontally laminated pebbly sandy gravel (Gh). The lamination is diffuse. The bed is cut by a lot of faults.

1-1,5 m laminated sand with a lot of intraclasts of silty clayey diamicton (Sh, Dm). The bed looks like a breccia with angular cubes of silty clayey diamicton in a matrix of sand.

1 m horizontally laminated sand and coarse silt (Sh).

Section 2

Section 2 is situated about 25 m north of section 1 and starts about 5 m above the level of lake Vättern (+88,5 m, Fig. 102).

2,5 m horizontally laminated sand and coarse silt (Sh).

The unit is coarsening upwards.

In the lower part of the unit there are water escape structures. The upper contact is

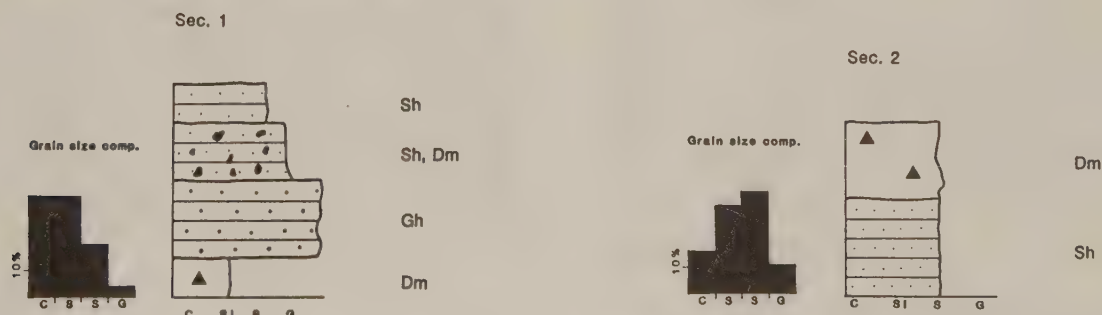


Fig. 102. Log of section 1 and 2 from Warpa skans.

erosive and streaks of incorporated sand can be seen in the lowest part of the overlying sediments.

2,0 m redbrown sandy silty diamicton (Dm). In the lower part of the bed the texture is coarser and the gravel fraction seems to be dominating. There are many lenses of sorted material in the unit. In the contact to underlying sediments there are streaks of sand incorporated from underlying sand. The streaks are pointing towards the south. The rock fragment composition in the diamicton is about 90% Visingsö Group of Rocks and 10% crystalline rocks.

7:13:2 Discussion

The lowest silty clay diamicton has the same properties and stratigraphic and geographic position as the Rosenlund diamicton and was thus correlated with the Rosenlund diamicton. The overlying gravel is deposited in a fluvial stream. The topographic and stratigraphic position of the unit indicates deposition under a glacier alternatively in a deep glacial lake close to the glacier margin. The texture and erosion of underlying sediments is likely in the subglacial environment but is also possible in a proglacial position. In the literature there are examples of faintly laminated gravel, deposited by sediment gravity flows, they have eroded in underlying cohesive sediments (Fisher and Mattinson 1968, Walker 1975b).

The breccia-like deposit is probably a collapsed undercut glaciofluvial channel wall. The diamicton pieces were transported a very short distance, probably in suspended sand. Undercutting of channel walls can perhaps also explain the faulting in the underlying unit. The erosion of the underlying unit of silty clayey diamicton shows many similarities to the Rosenlunds bankar, which lie less than 4 km south of the site.

The lowest unit in section 2 was deposited in low energy water close to a glaciofluvial channel carrying a lot of suspended sediments. The coarsening upwards indicates a more proximal position relative to the sediment source. The upper contact is erosive and sand was incorporated into overlying diamicton, indicating shearing when the diamicton was deposited. Incorporation of underlying sediments has been observed in sedimentary gravity flows (Middleton 1967, Lawson 1979) and in the subglacial environment (Boulton 1974a). The slope in the area runs roughly towards the west, which is the most likely direction in which a sediment gravity flow would have traveled. The incorporated sediment streaks are pointing towards the south, indicating that the shearing and incorporation was probably caused by an overriding glacier. This does not necessarily indicate that the diamicton is a lodgement till. The diamicton could be a waterlain sediment sheared by an overriding glacier. The rock fragment composition of the two diamictons in the section is similar, but the texture difference and the stratigraphic position indicate that they belong to different stratigraphic units.

7:13:3 Conclusions

The silty clayey diamicton in the lowest part

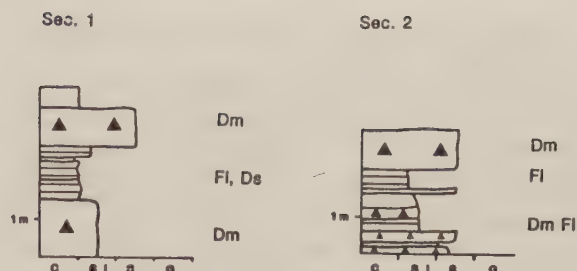


Fig. 103. Log from 500 m SV of Vista kulle.

of section 1 is correlated with the Rosenlund diamicton, because the diamicton has similar stratigraphic and geographic position, texture structure and color. The diamicton has been eroded by a glaciofluvial stream, depositing sand and gravel with a lot of intraclasts. The sediments were deposited in a subglacial tunnel or just in front of the grounding line of the glacier. The sandy gravel and overlying laminated sand and silt is correlated with the Sanna beds. This is confirmed by the stratigraphic- and geographic position, the inferred paleoenvironmental interpretation and the erosion of the substrata.

The Sanna beds are superimposed by a redbrown sandy diamicton with evidence of shearing by a grounding glacier. The unit is correlated with the Öxnehaga diamicton, due to the stratigraphic position, the texture similar to the substrate and the color.

7:14 500 m southwest Vistakulle

About 500 m southwest of Vistakulle there is a small cliff (Fig. 25). Two sections are described. Section 1 is about 10 m south of section 2. The sections start at the level of lake Vättern (+88,5 m). The sections are described from bottom to top (Fig. 103).

7:14:1 Sections

Section 1

1,5 m bluish gray silty clayey diamicton (Dm). There are many lenses of sand and silt in the bed. The diamicton is jointed with iron and manganese oxides precipitated in the fractures.

0,5 m red laminated clay with thin laminae of sand (Fl). The unit is jointed with iron oxides precipitated in the fractures.

0,4 m contorted laminated clay and silty diamicton (Fl, Ds).

0,1 m red massive clay (Fm).

0,3 m contorted laminated clay, silt and sandy silty diamicton (Fl, Ds).

1,0 m redbrown sandy silty diamicton (Dm). There are many light gray spots and subvertical wedges in the bed. Lenses of silt are common. The diamicton is compact.

0,5 m red laminated clay (Fl).

-scree

Section 2

Section 2 is situated about 10 m north of

section 1. The section starts at the level of lake Vättern (+88,5 m).

0,2 m gray sandy silty diamicton (Dm). The rock fragment composition is about 86% Visingsö Group of Rocks, 12% crystalline rocks and 2% Paleozoic limestone. The unit is probably involved in a fold (Fig. 103).

0,05 m contorted laminated gravely sand with some pebbles (Sh).

0,1 m Contorted laminated silt (Fl). Sub-horizontal wedges of overlying silty diamicton are interfingering with the overlying bed.

0,3 m sandy silty diamicton with unusually many clasts (Dm). The upper contact is erosional and lumps of the diamicton are found in overlying sediments. The rock fragment composition is 89% Visingsö Group of Rocks, 9% crystalline rocks and 2% Paleozoic limestone.

0,3 m very contorted laminated silt, with thin laminae of clay (Fd). In the lower part of the unit there is a thin lamina of sand. The lamina is deformed but looks like sinusoidal ripples. Between the sand lamina and the underlying diamicton, lumps and lenses of this diamicton are found in a silty matrix. Remnants of lamination are found in the silty matrix. The thickness of the clay lamina is increasing upwards.

0,25 m silty clay diamicton (Dm). The unit is more fine grained than underlying diamicton beds and contains few clasts.

0,4 m very contorted laminated silt (Fd). There are thin laminae of red clay in the upper part of the unit.

0,1 m contorted laminated fine sand with pebbles and intraclasts of clay or silty diamicton (Fl).

0,5 m contorted laminated silt and clay with some dropstones (Fl).

1,0 m reddish sandy diamicton (Dm).

7:14:2 Discussion

The laminated clay and the dropstones in the sections indicate that the sediments were deposited in a subaquatic environment. The diamicton beds in the lower part of the sections look like the Rosenlund diamicton and have about the same rock fragment composition, but the texture is somewhat coarser than the Rosenlund diamicton usually is. The thin diamicton beds seem to have been deposited by sediment gravity flows in a sub-aquatic environment. Undermelting is also a possible depositional process, but is less likely. The variation in texture and rock fragment composition favors the sediment gravity flow alternative. The diamicton bed about 0,4 m up in section 2, seems to wedge out towards the north and displays sub-horizontal wedges interfingering into underlying sediments, indicating plastic deformation by shearing, perhaps during a sediment gravity flow. The direction of shear has probably been towards the north. The lumps and lenses of silty clayey diamicton in the overlying silt might be pellets dropped from overturning icebergs (Ovenshine 1970). It is also possible that the silt is a cloud of sediment following a sediment gravity flow (Hampton 1975), alternatively a density modified grain flow (Lowe 1976b, Nemec et al. 1980). The intraclast could either have fallen into the silt from higher parts, or held in suspension by upward moving water ejected

from the flow below or by dispersive grain pressure from the particles in the cloud. The genesis of the uppermost sandy diamicton has not been possible to distinguish in the sections. The rock fragment composition of two samples shows great difference (70% resp 90% of Visingsö Group of Rocks) and the texture of the diamicton is very heterogeneous. The stratigraphic position, the sandy texture and the heterogeneity are the only properties indicating that the bed is part of the Öxnehaga diamicton.

The sediments in the section display extensive deformation. The deformation could have been caused by pressure from grounding icebergs, glaciotectionic pressure from a temporary grounding otherwise floating glacier, by lake ice or by gravity induced processes. If there is no connection between the Vättern basin and the glacial lake, the icebergs must have been about 120 m thick to be able to deform the sediments at the site. Icebergs of this size deforming bottom sediments have been reported by Vorren et al (1983), but this size icebergs were perhaps not likely in the small Vättern basin. If the glacier front was north of the Östergötland plain and if there was a connection between the Vättern basin and the Baltic Ice Lake the water depth of the site was about 10 m (Norrman 1964). This is a too shallow for deforming icebergs. Most of the shear structures indicate a shear force directed towards the north, which is inconsistent with a temporary grounding glacier. A grounding glacier in the Vättern basin should display glaciotectionic structures pointing towards the south. The deformation could also be due to density differences between the plastic sediment units. There are waterescape structures in the unit, but only to a minor extent. The deformation could also have been caused by the drag force from an overriding sediment gravity flow. A combination of waterescape and deformation by some massmovement appears most likely.

7:14:3 Conclusions

The silty clayey diamicton in the lower parts of the sections was perhaps deposited by sediment gravity flows in a subaquatic environment. The unit shows similarities to the upper part of the Rosenlund diamicton at Ryhov.

The deformation of the unit was formed by a combination of fluidized flow, when water escapes from the sediments, and drag forces from overriding sediment gravity flows.

7:15 Vidablick

Vidablick is situated about 1,5 km northeast of Bankeryd (Fig. 25). The section is about 10 m high and starts at the level of lake Vättern (+88,5 m) (fig 104).

1,6 m bluish gray silty clayey diamicton (Dm). The diamicton is very compact without lenses or laminae of sorted sediments. The bed is jointed with iron and manganese oxides precipitated in the fractures. Two parallel joint system are visible, one is subvertical, the other subhorizontal.

1,6 m bluish gray silty clayey diamicton (Dm). The diamicton is jointed but the joints are more closely spaced than in the underlying

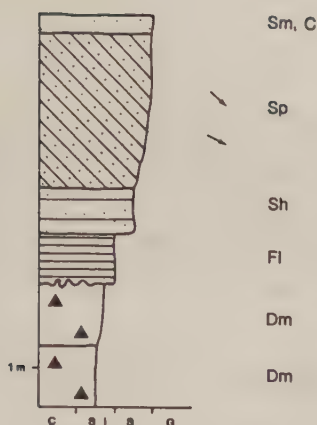


Fig. 104. Log from Vidablick.

ing unit. There are some lenses of water-sorted sand and silt in the unit. The upper contact is usually loaded, but at some places the diamicton seems to grade into overlying sediments.

1,3 m contorted laminated silt (Fl). There are lumps and lenses of underlying diamicton in the unit. The silt grades into overlying sediments.

1,2 m horizontally laminated fine sand and silt with thin laminae of clay (Sh). There are waterescape structures in the bed.

4 m planar-bedded cross-laminated sand with some laminae of silt (Sp). Thin and short laminae of clay have also been found in the unit. In the upper part of the unit, current ripples have been found. About 1 m up in the unit the laminae are dipping 10° towards 106° and 2 m up in the unit 19° towards 138° .

0,5 m massive sand with organic material (Sm,C).

7:15:1 Discussion

The lowest diamicton unit has the same properties as the Rosenlund diamicton.

The overlying diamicton bed, with laminated lenses of silt and sand, with a loaded or grading, upper contact was probably deposited in a subaquatic environment by undermelting of a floating glacier, an iceshelf near the grounding line (Orheim & Elverhøi 1981, Drewry & Copper 1981) or from icebergs. The grading upper contact suggests a successively more distal position relative to the glacier margin.

The overlying laminated silt is probably the bottomset bed of a delta.

The planar-bedded cross-laminated sand is the foreset bed in a delta deposited by Lillån entering lake Vättern (Norrman 1979, Svanteson 1985), with a paleocurrent towards the east.

The sediments were probably eroded in the Bankeryd valley.

The loaded and grading contact between the diamicton and the bottomset bed suggests an almost continuous sedimentation of glacially derived sediments. These are deposited in a glacial lake into a delta sedimentation in the lake Vättern when the waterlevel was at about +105 m.

7:15:2 Conclusions

The silty clayey diamicton in the bottom of the section has the same properties as the Rosenlund diamicton and is correlated with this unit. It is possible that the overlying diamicton with its lenses of sorted sediments is the deglaciation sediments of the glacier depositing the Rosenlund diamicton. The overlying delta belongs to the Ryhov sands and was deposited by a river flowing towards the east. The delta was deposited when the waterlevel was at about +105 m. (Norrman 1964, 1979).

8 The Tenhult valley

The Tenhult valley is a narrow trench bordered by steep fault walls (Figs. 4 and 5). The valley is about 1 km wide and 12 km long and runs in a north northwest-south southeasterly direction. The northern end of the valley is situated at +88 m at Huskvarna and the southern end is situated at the main waterdivide south of Tenhult at +220 m (Fig. 105).

Most parts of the valley, is covered by water-sorted sediments. Cohesive sediments are dominating in the valley but in the valley slopes coarser sediments are found. In the northern parts of the valley fluvial erosion has denuded older diamicton, sand and gravel units. In the southern end of the valley mounds of coarse sediments point through the cohesive sediments.

8:1 Mjälaryd

The site of Mjälaryd is situated in the



Fig. 105. Topographic map of the Tenhultsdalen valley.

southern end of the Tenhult valley. The site is a gravel pit cut into the valley side. The lowest part in the pit is at about +227 m and the highest part about +243 m (Fig. 106). Three sections are described. In each section at least two different stratigraphic units are found. The stratigraphic units can be traced between the different sections (Fig. 106).

8:1:1 Section 1

Section 1 starts at about +227 m and displays the three lowest units (Fig. 106, 107). The section wall strikes approximately northeast-southwest. The units are described from bottom to top.

0-1 m horizontally laminated sandy gravel (Gh). In the upper parts of the unit, the gravel has a matrix of silt and clay. The gravel is matrix supported and the stratification is diffuse. The grain size composition was analyzed in two samples showing sandy gravel with about 10% of fines. The rock fragment composition is analyzed in two samples showing 21 resp. 15% Visingsö Group of Rocks and 79 resp. 85% crystalline rocks.

There is evidence of shearing in the contact to overlying sediments.

3.7 m massive redbrown sandy diamicton (Dm). This unit can be divided into two subunits. The lower subunit is about 1.7 m thick. It is softer and somewhat lighter than the overlying subunit. The grain-size composition is remarkably homogeneous (Fig. 107) with 10% gravel, 70% sand and 20% fines (mean of six samples). The rock fragment composition varies between 16-18% with a mean of 18% Visingsö Group of Rocks and varies between 81-84% with a mean of 82% crystalline rocks. In one sample 1% Paleozoic limestone occurs. The lowest 30 cm of this subunit is more compact and is usually gray. Over this, the very bottom zone, there is a number of often deformed lenses and thin beds of mainly sand.

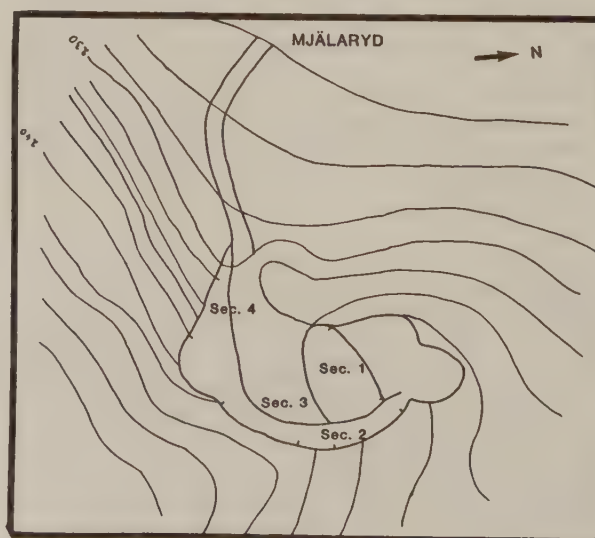


Fig. 106. Topographic map of Mjälaryd.

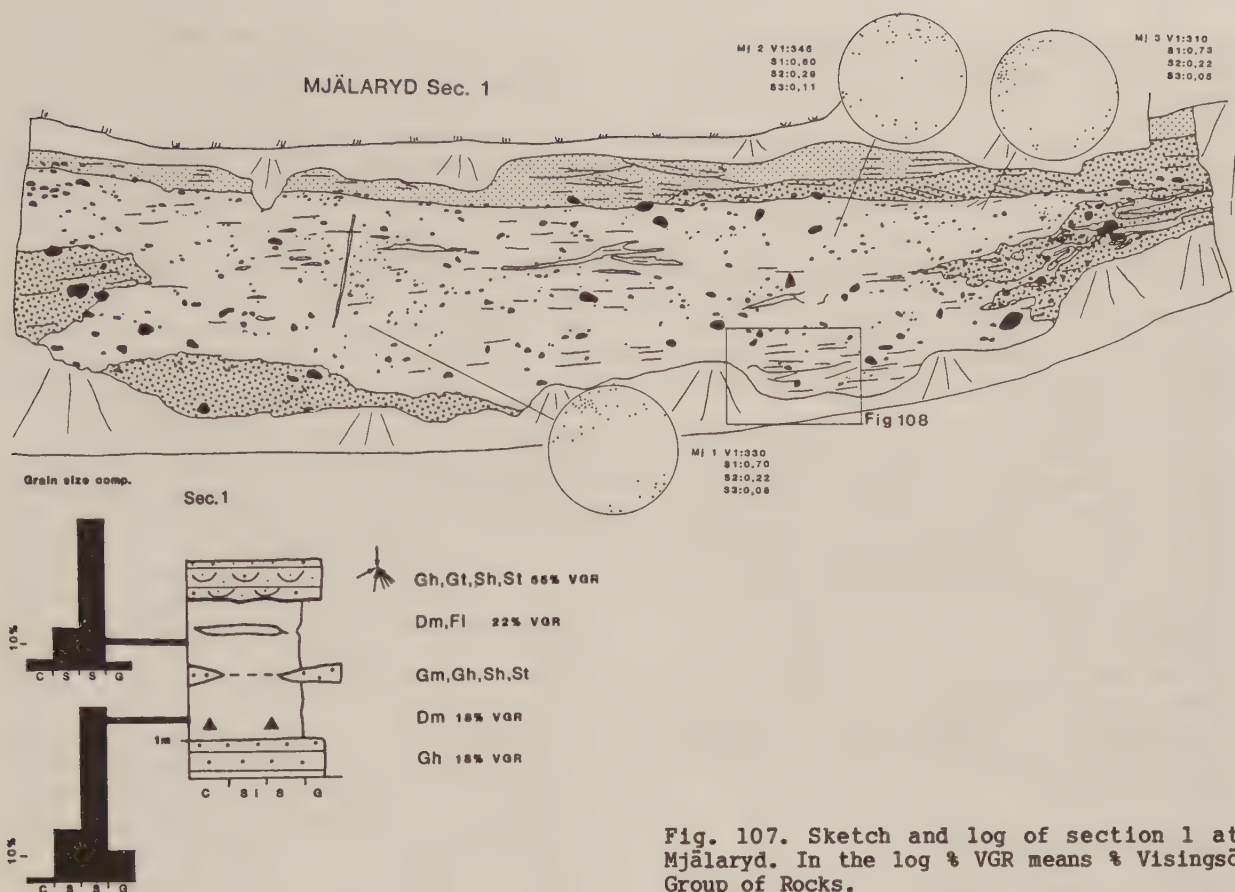


Fig. 107. Sketch and log of section 1 at Mjälaryd. In the log % VGR means % Visingsö Group of Rocks.

Silt, clay and redbrown fine grained diamicton units also occur (Fig. 108). Clasts in the unit have not deformed the underlying thin beds of sorted sediments, but these beds are often bent over clasts (Fig. 108). One fabric analysis of clasts long axes was made about 0,5 m up in the bed. Clasts long axes have a preferred orientation around 330° with a dip of about 15° ($S_1=0,7$, $S_2=0,22$ and $S_3=0,08$, Fig. 107).

The two subunits are often separated by a thin bed of gravely diamicton (Dm). In both ends of the section there are lenses of massive or laminated sand and gravel (Gm, Gh and

St) separating the two subunits.

The rock fragment composition of the sand and gravel lens in the southwestern end of the section is 19% Visingsö Group of Rocks, 80% crystalline rocks and 1% Paleozoic limestone.

In the northwestern end of the section there are lenses of gravel. The lenses are possible to trace far into the diamicton unit (Fig. 107). In these lenses of gravel there are thin lenses of diamicton of the same type as in the surrounding diamicton.

The rock fragment composition of two samples is 21 resp 16% of Visingsö Group of Rocks and 79 resp 84 % of crystalline rocks.

The lens in the southwestern end of the section consists of cross-laminated sand. In the contact to overlying diamicton the lamination is folded with a fold-axis dipping 20° towards 255° and the axial plane dipping in a southeasterly direction.

The lenses in the northeastern end of the section consist of horizontally laminated sand and gravel, often poorly sorted (Fig. 107). The lamination shows only minor deformation in the contact with the superimposing sediments (Fig. 107). The wedge of diamicton between the wedges of gravel in the northeastern end of the section (Fig. 107) displays evidences of erosion on the upper surface. Gravel clasts from the substrata are incorporated in the diamicton wedge.

The upper diamicton subunit is massive, redbrown and sandy (Dm). This diamicton unit has a slightly higher content of gravel and fines (Fig. 107) compared with the underlying subunit.

The rock fragment composition varies between 15-29% with a mean of 22% Visingsö Group of

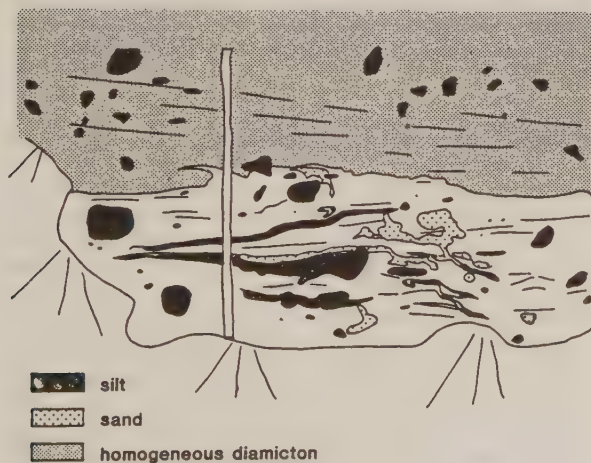


Fig. 108. Detail from section 1 at Mjälaryd.

Rocks and 85-71% crystalline rocks with a mean of 78% (seven samples). The content of Paleozoic limestone is always less than 1% in the subunit.

This subunit is usually homogeneous, but approximately 1,3 m up in the unit, there is a zone of lenses of sand, silt, clay and clayey diamicton. The lenses are deformed but primary sedimentary structures are visible.

Two fabric analyses were made in the upper subunit (Fig. 107) 10 and 40 cm below the top of the unit. The upper analysis shows a good preferred orientation of about 315° with a dip of about 10° (Fig. 107). The lower analysis has an almost random orientation of clasts long axes.

The upper surface of the subunit displays evidence of fluvial erosion.

0,5-1 m horizontally and trough-bedded cross-laminated sand and gravel (Gh,Gt,Sh,St). In the contact to the underlying unit pebbles are clustered. Two samples were collected in this unit. The rock fragment composition is 49 resp 60% Visingsö Group Rock, 47 resp 35% crystalline rocks and 4 resp 5% Paleozoic limestone.

The maximum dip of the foreset laminae of trough-bedded cross-laminated sand and gravel was measured in 7 spots in the unit (Fig. 107). Six out of seven measurements display a paleocurrent towards the northern sector.

Discussion of section 1

The lowest sand and gravel unit was probably deposited in a fluvial environment. The upper parts of the bed show high amounts of silt and clay, and the gravel is matrix supported. This indicates that this part of the bed was instantaneously deposited, probably by freezing (Middleton 1967 and others). The sediment was probably transported as a debris flow or a modified grain flow (Lowe 1976 a). Transportation in super critical flow in a glacier conduit is also a possibility.

The sediment was probably deposited close to the glacier, at a proximal outwash plain or into a low energy water. The water was probably shallow, because the sediment is situated at least 5 m above the col to the south which is less than 1 km away (Fig. 2). Subglacial deposition of the sediment is possible but not likely, because the competence of the glaciofluvial stream would not have been lowered before the stream is outside the tunnel (e.g. Åmark 1984).

The shear structures in the upper parts of the sand and gravel unit was formed either by subglacial shearing or by the shearing of a passing high energy sediment gravity flow. The gradational contact to the overlying diamicton unit indicates that sediments were incorporated into the basal parts of the glacier or into a sediment gravity flow (Miall 1983). A fabric analysis in the lower parts of the overlying diamicton (Fig. 107) indicates a direction of shear from 330° .

The very bottom of the lower subunit of the overlying diamicton is massive. The upper part of this diamicton subunit has lenses and thin continuous beds of sand silt and clay. The thin beds are conformably bent over the clasts (Fig. 108). Deformations under the clasts are rare. This indicates that the thin beds were formed before they were let down on top of the clasts. This is, according to Shaw and Archer (1979) diagnostic of basal meltout

till. This, together with the shear structures in the lower contact zone, suggests that the lower subunit of the diamicton and the uppermost parts of the underlying gravel (the contact zone) were deposited at the base of a glacier. The lower subunit is perhaps a basal meltout till. The lowermost massive part of the subunit may be a lodgement till. The fabric analyses in the lower parts of the subunit indicate a direction of shear towards 150° , which is the likely direction of an advancing glacier.

The lenses of gravelly diamicton, separating the two diamicton subunits, might be a horizon of winnowing of fines from the diamicton surface, indicating an episode of subaquatic or subaerial environment.

The lenses and wedge formed units of gravel and sand in the both ends of the section are also connected with the boundary between the two diamicton subunits. The complex system of interfingering diamicton and gravel beds, in the northeastern end of the section could have been formed by intermittent fluvial deposition and deposition of diamicton by sediment gravity flows. Particles from the wedges of sand and gravel are incorporated into an overlying diamicton unit, which favors this.

The folding of the trough-bedded sand in the lens in the south-western end of the section (Fig. 107), indicates shearing from a northern sector. The formation of this kind of folding is possible from the drag of a passing debris flow or by the shear of a moving glacier. A subglacial deformation might have occurred either contemporary with the sedimentation of overlying deposits alternatively the shear stress was transmitted through a unit of already deposited sediments. It is possible that the lower part of the upper subunit was deposited by sediment gravity flow processes and that the upper part of the upper subunit was subglacially deposited. The fabric analysis, with an almost random orientation of clasts longaxes, 50 cm down in the subunit and a preferred orientation in the upper part of the subunit might suggest this (Fig. 107).

The upper surface of the diamicton unit shows evidence of fluvial erosion. In the lower part of the upper sand and gravel unit, there is a lag of pebbles confirming the erosion. The sand and gravel unit shows paleocurrents towards the north.

The unit shows a very high amount of Paleozoic limestone (4-5%, which indicates the sediment was derived from a far traveled diamicton.

Environmental interpretation of section 1

Most likely, the lowest unit of sand and gravel was deposited in a proglacial environment, perhaps in a shallow water.

Later a glacier might have passed over the area and a basal till (the lower diamicton subunit) was deposited. During the following deglaciation water eroded the till, and lenses and thin beds of sand and gravel were deposited as well as sediment gravity flows (the upper diamicton subunit). It is possible that the whole diamicton unit was deposited by sediment gravity flows from glacier.

A lower diamicton with a very low content of Visingsö group of Rocks, found by Bjelm (1976) from this site, might be the basal

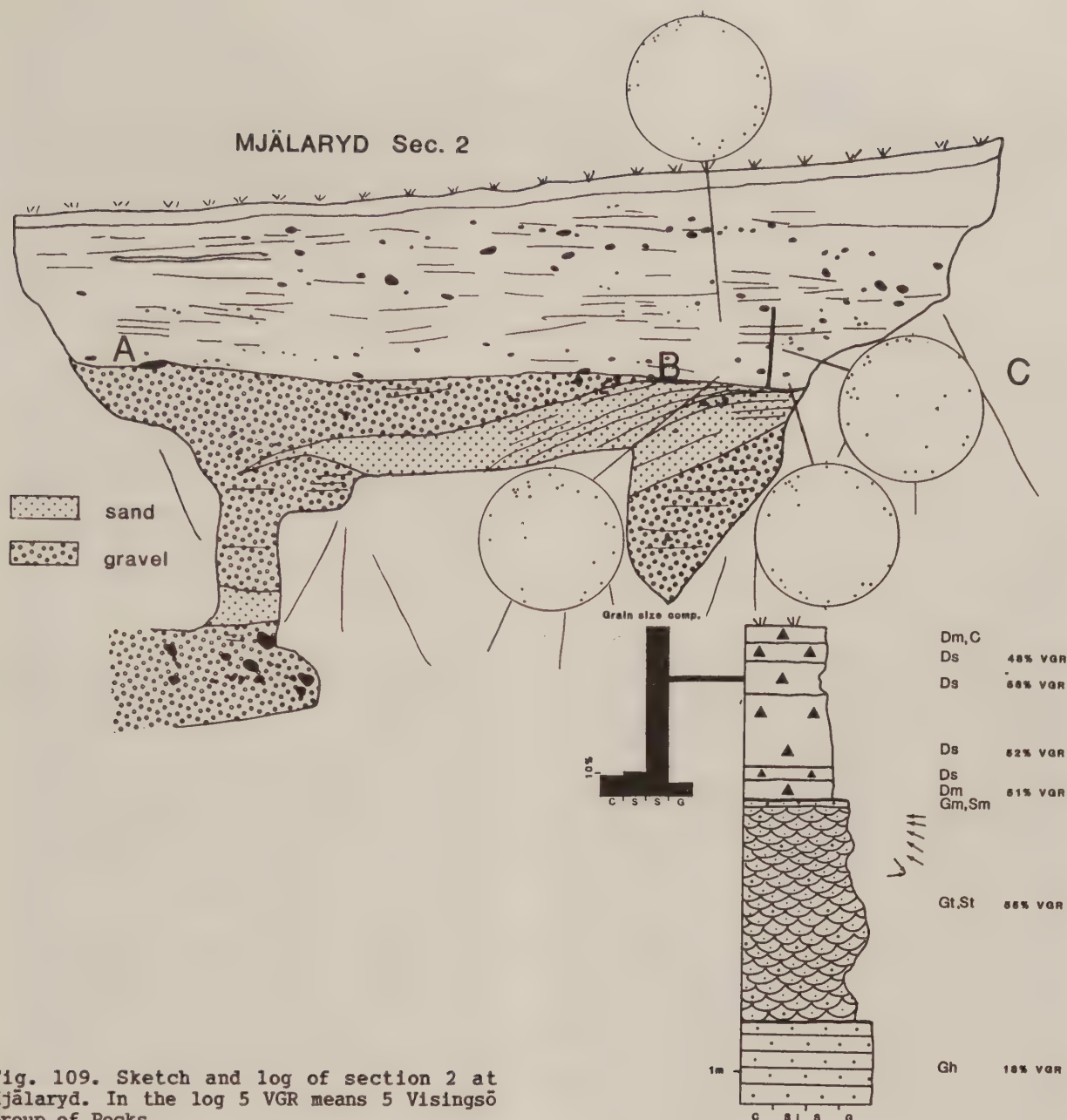


Fig. 109. Sketch and log of section 2 at Mjälaryd. In the log 5 VGR means 5 Visingsö Group of Rocks.

till from this glaciation, and the above described sediments were formed during the deglaciation.

Subsequent fluvial erosion formed an erosional lag on top of the upper subunit and the upper sand and gravel was deposited. The different rock fragment composition of the uppermost unit compared to the underlying units indicates that the sediment was derived either from a new glacier or from englacially transported debris.

8:1:2 Section 2

Section 2 is situated in the eastern part of the pit (Fig. 106). The section is almost perpendicular to section 1. The lowest parts of the section is a continuation of the upper and north-eastern parts of section 1 (Fig. 109). The section is described from bottom to top.

2.5 m pinkish gray horizontally laminated pebbly gravel (Gh), with a high content of silt. Thin lenses of sand and silt are also found in the unit. The rock fragment composition from two samples are 21 resp 16% Visingsö Group Rocks and 79 resp 84% crystalline rocks.

Boulders are clustered in the upper contact and the stratification was cut by fluvial erosion.

6.5 m trough-bedded cross-laminated gravel and sand (Gt, St).

The rock fragment composition of four samples is 60, 57, 53 and 49% (with a mean of 55%) Visingsö Group Rocks, 35, 43, 44 and 47% (with a mean of 42%) crystalline rocks and 5, 4, 3 and 0 % Paleozoic limestone. The samples with 0 and 3% Paleozoic rocks were collected in the top of the unit and the others are collected in lower parts of the unit (Fig. 109).

The maximum dip of the cross-laminated sand

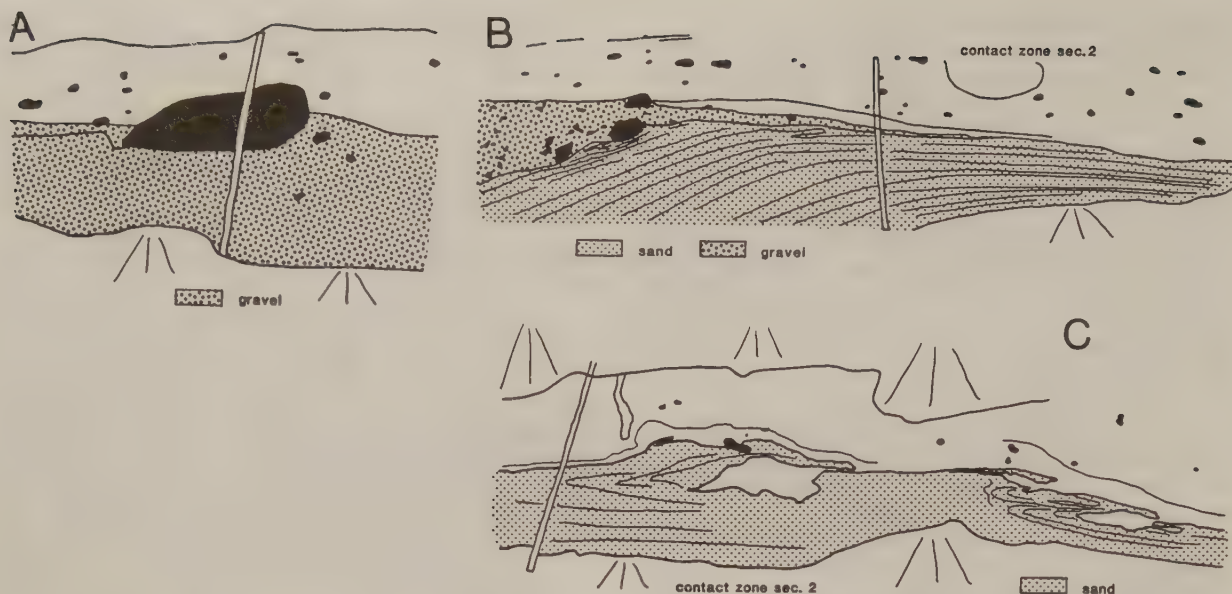


Fig. 110. The contact zone between the gravel and the diamicton in section 2.

and gravel were measured at seven different spots and are 14° towards 84° , 4° towards 142° , 20° towards 302° , 21° towards 299° , 34° towards 294° , 20° towards 279° and 13° towards 273° . All measurements were made in the upper parts of the unit.

In the contact to overlying unit, there is an about 10 cm thick zone of massive sand and gravel. In this zone, the sediment shows shear structures (Figs. 109 and 110). From this zone, thin laminae of sand and gravel are possible to trace up into the overlying unit of diamicton. Below the zone isoclinal folds are found at some places (Fig. 110). The foldaxes of two folds dip 10° towards 80° and 10° towards 98° . The folds are open towards the south. About 1 m down into the unit, the lamination south of the bigger clasts was deformed (Fig. 110) by a shear force coming from a northern sector. In the upper surface of the unit a track was cut by a boulder from overlying unit. The direction of the track is $0-180^{\circ}$.

The upper contact of the unit gives a sharp impression due to precipitated iron and manganese oxides in the lowermost parts of the overlying unit.

0,6 m massive yellowish brown sandy diamicton (Ds).

The rock fragment composition of two samples is 45 resp 57% Visingsö Group of Rocks and 55 resp 43% crystalline rocks.

In the contact to underlying unit there are precipitated iron and manganese oxides. Thin beds of sand and gravel can be traced from the underlying unit up into the lower parts of the bed. Streaks of the unit are projecting down into underlying sand and gravel. One of the streaks was dug out and shows a foldaxis dipping 10° towards 90° . The fold is open towards the north (Fig. 110).

Clasts lying in the contact to underlying unit often show diamicton under the northern end of the clasts, while south of the clast, sand and gravel from below are traceable to the upper surface of the clast (Fig. 110) even if the clasts are imbricated towards north. One boulder in the contact has cut a

track into the underlying unit. The direction of the groove is $0-180^{\circ}$. The long axes of the boulder dip 6° towards 330° . The configuration of the contact between the two units is shown in Fig. 110.

Fabric analyses were made at three spots in the unit (15,20 and 35 cm above the lower contact). The graphic configuration of the analyses is shown in Fig. 109. All analyses display a direction of clast long axes of $135-315^{\circ}$. A composite of the three analysis gives a preferred orientation of 325° with an inclination of 6° ($s_1=0,58$ and $S_2=0,34$ $S_3=0,08$).

0,4 m stratified yellow and brown sandy diamicton (Ds). The stratification is faint. A thin bed of sand in the unit dips 11° towards 31° . A fabric analysis was made in the unit, showing a preferred orientation of clasts long axes of $130-310^{\circ}$ with an inclination of 3° towards the northwest (Fig. 110).

2,2 m stratified yellowish brown sandy diamicton (Ds). There are many thin beds and lenses of sand, the sand beds are sometimes laminated.

The rock fragment composition is 52% Visingsö Group Rocks and 48% crystalline rocks.

1,0 m alternating thin beds of stratified sandy and clayey diamicton (Ds). The thin beds of sandy diamicton is yellowish brown and the clayey diamicton is redbrown.

The rock fragment composition is 58% Visingsö Group Rocks and 42% crystalline rocks.

Big clasts are common in the bed. The stratification under the clasts is bent down, but only to a minor extent.

0-0,6 m stratified yellowish brown sandy diamicton (Ds). The diamicton is extremely sandy (about 75% Fig. 110). There are very few clasts in the unit.

The rock fragment composition is 48% Visingsö group rocks and 52% crystalline rocks.

The whole unit displays a fine stratification. Flow noses and water-escape structures are observed in the unit.

The unit wedges out towards the north.

0,5 m soil

Discussion of section 2

The lowest unit in the section displays a quite different rock fragment composition, compared to the overlying units. The erosional surface of the unit indicates a hiatus in the sedimentation.

The rock fragment composition of the upper gravel bed, displays an unusually high amount of Paleozoic limestone (4-5%). According to Gillberg (1965) the southernmost find of 5% cambro-silurian rocks in the diamicton is in the vicinity of Gränna about 60 km north of Mjälaryd.

There are two ways to explain the difference in rock fragment composition of the two gravel beds in section 2.

In the first case, the two glaciofluvial units were deposited by the same glacier, and the difference in rock fragment composition is explained by a derivation of material from successively higher parts of the glacier, and thus further traveled. This is possible during the melting of a glacier. However this can not explain the abrupt change from low to high amount of Visingsö Group of Rocks. It is possible that the glaciofluvial stream, suddenly shifted to another tunnel, and started to erode new material, but a shift of the subglacial tunnel in the narrow Tenhult valley should not give such an abrupt change in the rock fragment composition. A sudden change from subglacial derivation to supraglacial derivation of debris is also possible but not likely.

In the second case a new glacier, with a different rock fragment composition, advanced over the area. This glacier carried a higher amount of Visingsö Group of Rocks. The high amount of Paleozoic limestone might have come from erosion of the uppermost, furthest traveled parts of underlying diamicton.

The maximum dip of foreset laminae in the sand is measured at several places indicating paleocurrents towards the west or the westnorthwest.

In the contact zone to the overlying diamicton the stratification is absent and shear structures occur. Thin laminae of sand and gravel are possible to trace up into the overlying diamicton unit. This indicates that the sand and gravel was incorporated during or just before the diamicton was deposited.

Streaks from the overlying diamicton project down into the contact zone. The streaks are usually dipping towards the north (Fig. 110). Under the shear zone, isoclinal folds (Fig. 110), open towards the south, often occur. All the shear structures indicate a shear stress on the sand and gravel unit directed towards the south. Shearing, folding and incorporation of underlying sediments are properties usually related to basal till deposition.

The lower diamicton unit in section 2, is rather homogeneous. The lenses of sand in the unit are all very deformed. The rock fragment composition is about the same as in the underlying unit, which suggests a possible deposition by the same glacier.

There are two possible ways of deposition of the lower, 0,6 m thick, diamicton unit. In the first way the diamicton unit was deposited by a thick debris flow moving southwards (upslope). The second way of deposition is beneath a glacier. The consistent direction of shear and the topographic

position of the site favors the second way of deposition.

The erosion and deformation took place in the interface between the glacier sole and the substratum or between an already deposited diamicton unit and the substratum. The preservation of the incorporated sand and gravel laminae indicate a shearing of an already deposited diamicton unit or that the unit is a basal melt out till.

The overlying diamicton unit is laminated. The lamination dips towards the north-east, which is close to the direction of the slope. A fabric analysis in the unit, displays a preferred orientation of clasts long axes in 130-310° with an inclination of only 3°.

The superimposed diamicton is stratified and extremely sandy. There are many lenses of sorted sand in the unit. The high amount of sand indicates winnowing of fines. The stratification, the winnowing of fines and the fact that an overlying unit was deposited in a subaquatic environment favors a subaquatic deposition either by debris flow or falling out of suspension, rather than deposition in subaerial environment by sediment gravity flows.

The overlying unit is stratified with alternating beds of sandy and clayey diamicton. The rock fragment composition indicates the same source of material as for the underlying diamicton units.

The lamination is deformed under clasts, indicating that the clasts are dropstones. This, together with the stratification, indicates deposition in water. The alternation might be a seasonal effect.

The uppermost diamicton unit displays a clear stratification. Flownoses and other structures indicate a deposition by debris flows. The wedging out of the unit is due to secondary erosion.

8:1:3 Section 3

Section 3 is situated in the central parts of the pit (Fig. 106). The section strikes approximately north-south. The section starts at about +227 m (in a dug hollow, not shown in Fig. 111) and reaches about +243 m (Fig. 111).

8,5 m trough-bedded cross-laminated gravel and sand (Gt,St). There are many pebbles in the bed. The gravel and sand display a fine tail in the grain size composition.

The rock fragment composition of two samples is 58 resp 55% Visingsö Group rocks, 38 resp 45% crystalline rocks and 4 resp 0% Paleozoic limestone. The sample without Paleozoic limestone was collected close to the upper contact.

The maximum dip of the laminae in the trough-bedded sand and gravel was measured at four different spots. The directions are shown in Fig. 111.

In the upper part of the bed the stratification is folded. The folds are open towards the south (Fig. 111,112). In the contact to the overlying unit the sand and gravel are homogenized and display shear structures. Thin laminae of sand and gravel are possible to trace up into the overlying unit. Streaks of overlying diamicton unit project down into the upper part of the sand and gravel.

1,0 m massive brown sandy diamicton (Dm). The grain-size composition is coarser in the lowermost part of the unit than elsewhere in

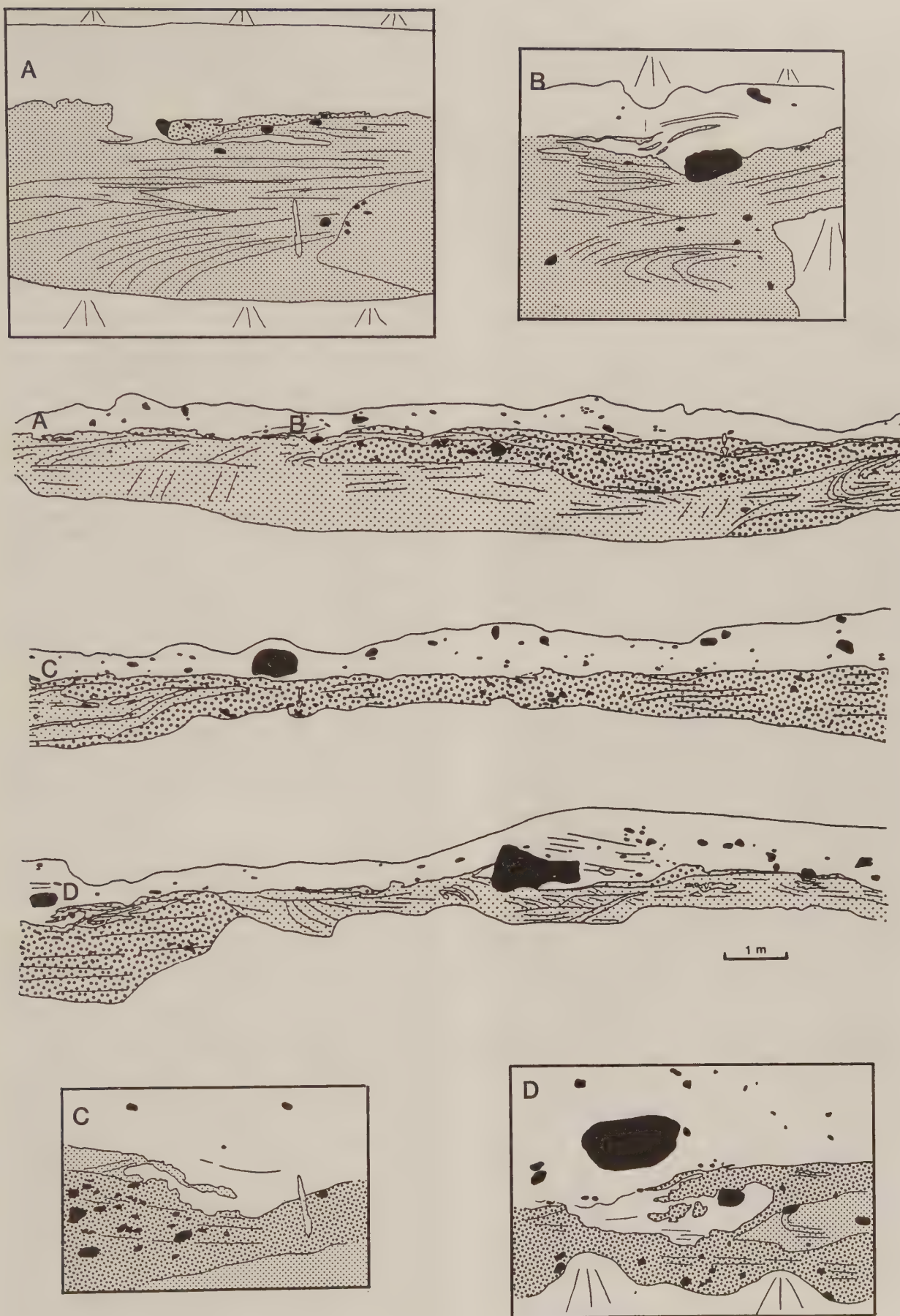


Fig. 112. The contact zone between the gravel and the diamicton in section 3 at Mjälaryd.

44% crystalline rocks.

Thin beds below boulders are often bent down. One fabric analysis was made in the unit showing an orientation of clast long axes around 10° with a dip around 8° ($S_1=0,67$, $S_2=0,25$ and $S_3=0,08$). The upper contact is interbedded.

3,5 m stratified yellowish brown sandy diamicton (Ds). In the unit there are many lenses of sand, coarse silt and a more fine grained diamicton. Especially in the lower part of the unit there are many often deformed lenses of laminated sand, especially in the lower part (Fig. 111).

The rock fragment composition of two samples is 53 resp 51% Visingsö Group of Rocks and 47 resp 49% crystalline rocks.

The stratification in the unit is dipping 14° towards 308° .

Several clastic dikes are found in the unit. The dikes are just a few cm wide, but dikes more than six meters high are found. In the central part of the dikes there is often a thin lamina of sorted sand. Otherwise there is usually a massive or faintly stratified diamicton of the same kind as the diamicton in the unit. The stratification of the dikes is parallel to the walls of the dikes. One of the dikes strikes $79-259^{\circ}$ and dips 40° towards the south. Another dike was possible to trace from the underlying unit (Fig. 111). It ends at the ground surface in a structure looking like a mud-volcano.

0,4 m massive sandy diamicton with organic material (Ds,C).

Discussion of section 3

The gravel and sand in the lowermost unit in the section, show a fine tail in the grain size composition, which is typical of glaciofluvial sediments (Folk and Ward 1957). Trough-bedding usually indicates deposition by flowing water in a braided stream, a shallow water or in a jetstream entering deep water. It is thus likely that the sand and gravel unit was deposited proglacially close to the glacier.

The contact to the overlying unit shows evidence of shearing. In a 10-20 cm thick zone, the gravel and sand is totally reworked and below, the primary sedimentary structures often are folded by a force from a northern sector. Thin laminae of sand and gravel are traceable from the sand and gravel unit up into the overlying diamicton. In the diamicton, these laminae are always dipping towards the north (Fig. 111) indicating that the diamicton unit was transported towards the south when the sand and gravel laminae were incorporated. This kind of incorporation is described from debris flow deposits by Lawson (1979) and Miall (1983), but usually, the contacts between sediment gravity flow are sharp, and display no deformation of underlying units. From subglacial deposits incorporation of underlying units from subglacial deposits are described by Boulton (1970a) and others. Extensive folding of underlying frictional sediments and a total reworking of an up to 20 cm thick zone is not described from sediment gravity flow deposits. The direction of shearing was towards the south, which is upslope. A sediment gravity flow from the glacier would lose energy close to the glacier margin and would not have capacity to deform and fold

underlying frictional sediments or carry boulders, which were deforming underlying sediments. In debris flows boulders are usually not in the bottom of the flow. Most likely the deformation and incorporation occurred subglacially. The diamicton was deposited either, by lodgement- or by a melt-out process. The deformation and incorporation was either formed during the deposition or by a shear force transmitted through already deposited sediments. The preservation of the thin laminae of incorporated sediments in the diamicton unit favors deposition by melt-out. Incorporation could also have occurred after the deposition of the lower part of overlying diamicton unit. It is likely the diamicton bed is a basal till.

The overlying diamicton bed has a lot of lenses of sorted material. The frequency increases upwards, which is expected in a melt-out till. The preferred orientation of the clast in the unit is 345° , which is the same direction as the striae and the drumlins in the vicinity, also suggesting subglacial shearing. These two proposed units of melt-out till are together about 3 m thick. According to Paterson (1969) it will take about 500 years to meltout these units by the geothermal heat alone, but flowing meltwater and melting from above, will increase the rate considerably.

The genesis of the overlying faintly laminated unit is not obvious but deposition by a sediment gravity flow process seems likely.

The unit of alternated bedded sandy and clayey diamicton, contains several thin beds of silt and clay. This indicates deposition in subaquatic environment and also suggests that the thin beds of diamicton were deposited by debris flows. The shape of the unit, wedging out towards the north, and the preferred orientation of clasts long axes around 0° , indicate that the flows came from the glacier in the valley and not from the hill to the south and to the east of the section.

The uppermost diamicton unit has a different configuration and grain-size composition than the underlying unit. Deformed lenses of sand are frequently found in the unit. Clay and silt beds are not observed. The stratification of the unit dips towards the north and a flow nose (Fig. 111) points towards the northern sector. Under the few boulders in the unit, the stratification is deformed, indicating the clasts were dropped or have sunk after deposition.

The structures of the unit indicate deposition by sediment gravity flows. The lack of lenses of thin beds of silt and clay, compared to underlying unit, suggest deposition in a different environment. The unit was either subaerially deposited, and the material was derived from the slopes south and east of the section or the unit was subaquatically deposited. In the latter case the rate of sedimentation was higher and/or the water was shallower, compared to the underlying unit.

The clastic dikes in the unit are interpreted as water extrusion channels. The dikes were formed when the pressure of the overburden became too high and when the pore water was expelled through the sediments. The ejection of porewater could simply be due to a fast aggradation of overlying sediments. It could also be due to a sudden drop of the ground

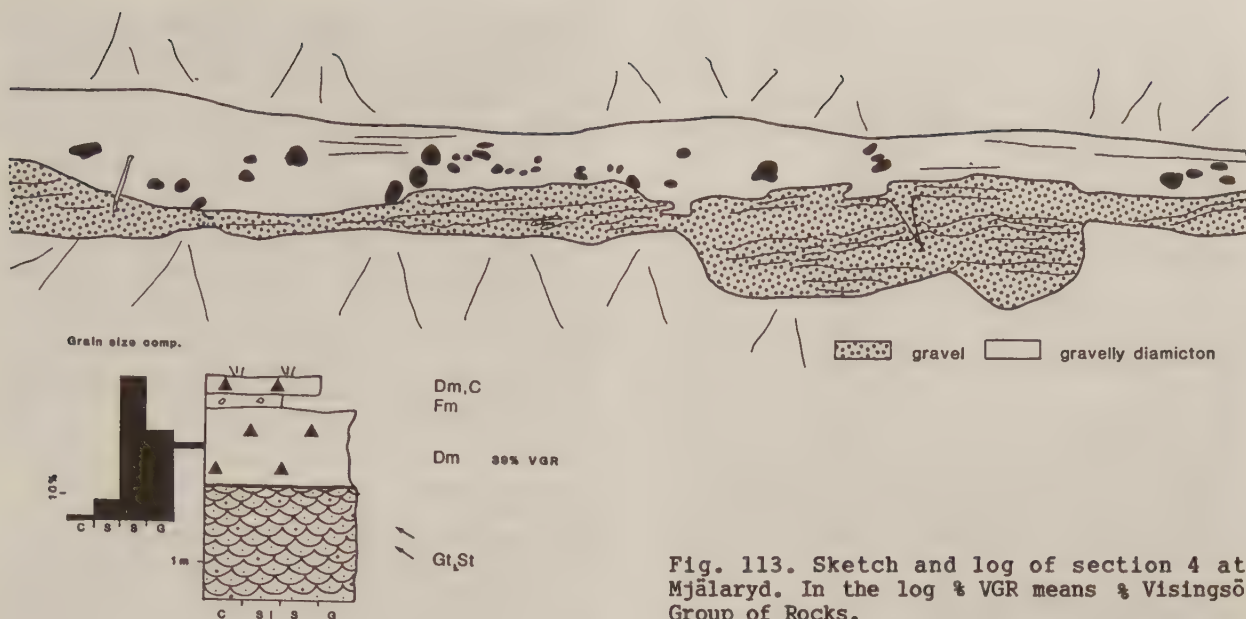


Fig. 113. Sketch and log of section 4 at Mjälaryd. In the log % VGR means % Visingsö Group of Rocks.

water table, causing a fast dewatering of the uppermost, extremely sandy diamicton. This dessication caused a sudden raise of the pore-water pressure in the underlying unit with its alternating beds of clayey diamicton and sandy diamicton, where the pore-water was less movable. The sudden rise of pressure leads to an ejection through overlying sediments.

The diamicton could have been deposited in a subaerial as well as in a subaquatic environment. The difference compared to the underlying unit speaks in favor of subaerial deposition. The fine lamination and the clastic dikes favor deposition in a subaquatic environment.

8:1:4 Section 4

Section 4 is situated in the southernmost part of the pit (Fig. 106). The section starts at about +232 and is described from bottom to top (Fig. 113).

3,0 m trough-bedded cross-laminated pebbly gravel (Gt), with some thin beds of sand and silt. The gravel usually has a fine tail of silt.

In the unit there is a fossil ice-wedge (Fig. 114). It is about 1,5 m high and 0,4 m wide at the top. The wedge can be traced to the top of the bed but no higher. On both sides of the wedge the lamination is disturbed. In the wedge, the gravel is laminated parallel to the walls of the wedge.

The maximum dip of the cross-lamination was measured at two spots in the unit and are 27° towards 304° resp 11° towards 296° .

The upper contact of the unit is conformable, but at some places deformed.

0-2,0 m massive or sometimes stratified gravelly diamicton (Dm, Ds). The diamicton becomes more fine-grained and more clearly stratified upwards. There is, for the area, an extremely high content of clasts in the unit. The clasts show a high angularity. There are many lenses and thin beds of sand and silt in the unit. The lenses and thin beds are usually deformed.

The rock fragment composition is 39% Visingsö

Group of Rocks and 61% crystalline rocks (two samples).

Boulders in the unit are projecting down into the upper part of the underlying unit and are deforming the internal stratification of the sand and gravel.

Lenses of undeformed stratified sand are found below the boulders (Fig. 113). These



Fig. 114. The Ice-wedge in section 4 at Mjälaryd.

lenses are usually found in the lower part of the unit.

The bed is tapering towards the west (perpendicular to the contour lines).

0-0,4 ■ massive silt (Fm). The unit is only found below +236 m.

0,6 ■ Soil.

Discussion of section 4

The fossil ice-wedge in the glaciofluvial unit, indicate that the unit was permanently frozen some time after deposition. The unit was thawed before overlying diamicton was deposited.

The overlying diamicton is coarser and has a higher content of crystalline rocks. The clasts are more angular and display more lenses of sorted material, than the diamicton in the same stratigraphic position in the other sections. There are many ways to interpret the unit, 1) the unit is an incompletely sorted glaciofluvial sediment, 2) the unit is originally a diamicton, which was washed after deposition, 3) the unit is a till consisting entirely of picked up coarse glaciofluvial sediments, 4) the unit is the result of one or many sediment gravity flows, coming from the glacier margin or from the slopes south or east of the section or 5) the unit is a meltout till. The clasts are usually angular, which rules out the first and the third alternative. There is no lag on top of the unit, which there would be in the second alternative. Sediment lenses with primary sedimentary structures below boulders are, according to Shaw (1977a, Haldorsen and Shaw 1982) a diagnostic criterium of melt-out till. The high angularity of the clasts suggests that the sediment was derived from supra glacial debris, which favors the sediment being either a supra glacier melt-out till or the result of sediment gravity flows from the surface of the glacier.

It would take years of perma frost to develop ice-wedges of this size. A fossil ice-wedge is only found in this position and not elsewhere in the site, where the overlying diamicton units are thicker and have properties more normal to the area. This might suggest a different genesis of the diamicton compared to the diamicton in the same stratigraphic position in the other sections, which are interpreted as till deposits. This, together with the unusual grain size composition, the existence of the ice-wedge and the tapering of the unit, favors the interpretation of the unit being either a sediment gravity flow deposit or a lag-deposit (own experiences from Svalbard) of sediment gravity flows. The lenses of sorted material below the boulders could have been formed when the boulders were heaved by the frost or by lake ice.

The fossil ice-wedge is filled with sorted sand and gravel indicating that it was formed before overlying unit was deposited. This fact also indicates that the overlying unit is not a till, because the ice in the wedge should not melt close to an advancing glacier. Till is not depositing when the glacier is cold-based, but under warm-based or subpolar glaciers. If the diamicton bed is a till the ice in the wedge should melt under the glacier and be filled with diamicton and not with gravel. It is possible the ice-wedge was fossilized long before the diamicton was

deposited, but in this case there should be other ice-wedges in other parts of the site. Most likely the diamicton over the ice-wedge was formed by supra glacial melt-out or by sediment gravity flow processes of supra glacially derived material.

One of the main thresholds of the ice-dammed lakes in the Vättern basin is situated about 1 km south of the site. It is possible that the original deposit was eroded when an ice-lake drained through the col. When the site came over the water perma-frost prevailed in the area and ice-wedges were formed. It is possible that the overlying diamicton was an active layer (2 m thick), but it is more likely that the diamicton was deposited after the ice-wedge was fossilized.

8:1:5 Discussion

According to Bjelm (1976), three basal till units were visible in Mjälaryd. Bjelm's differentiations of units is based mainly on different rock fragment composition in the units. The lowest unit has, according to Bjelm 2%, Visingsö Group of Rocks, the superimposed unit, about 29% and the uppermost unit about 77%. The gravel unit (the upper) displays about 78% Visingsö Group of Rocks. The lowest diamicton unit in Bjelm's (1976) stratigraphy has not been found in this investigation. This unit is probably a diamicton of locally derived material. Diamicton units with this composition were found in other sites in the vicinity. Bjelm's second unit, with a rock fragment composition of 29% of Visingsö Group of Rocks would perhaps resemble to the upper subunit in section 1, which has a rock fragment composition that varies between 15-29% of Visingsö Group of Rocks with a mean of 22% (seven samples). The upper clayey sandy diamicton in Bjelm's (1976) stratigraphy is most likely the lowest diamicton unit in section 2 and 3, although the clay fraction is never higher than 4% (seven samples). The rock fragment composition varies between 45-60% Visingsö Group of Rocks, which is considerably lower than Bjelm's 77%. Bjelm has also a much higher value for the gravel unit, (78%) compared to this investigation (56%, mean of seven samples).

8:1:6 Depositional models

The lowermost gravel and sand unit has a homogeneous rock fragment composition around 20% of Visingsö Group of Rocks. The unit was probably deposited in front of an advancing glacier (see above).

The glacier advanced over the area and deposited the lowermost diamicton subunit. It was probably deposited at the base of the glacier. The overlying subunit shows evidence of subaerial or subaquatic deposition, and of subsequent subglacial shearing, perhaps during a short oscillation. The lenses of glaciofluvial sediment were probably deposited during the deglaciation of this glacier.

The superimposed unit of grayish black trough-bedded cross-laminated sand and gravel, has a rock fragment composition of about 55%. There is evidence of erosion in the contact to underlying units. The abrupt change in rock fragment composition and the

erosional contact, indicate deposition in front of a "new" glacier with a different rock fragment composition in the debris. The trough-bedding indicates subaerial deposition, but subglacial or subaquatic deposition is also possible. The "new" glacier advanced over the area and deformed the upper parts of the gravels and sands and deposited a basal till. Whether the superimposed diamicton unit is a basal melt-out till, a lodgement till or a subglacially sheared diamicton unit, is not clear.

The stratified diamicton units in section 2 and 3 are probably deposited by sediment gravity flow processes. The unit of alternating beds of sandy and clayey diamicton and the stratified units below were probably deposited in a local ice-dammed lake. If the overlying unit was subaerially or subaquatically deposited is not clear.

During the deglaciation, a lot of melt water from the glacier in the Vättern basin, passed over the area. It is likely that the flowing water eroded the valley sides. When the site came over the water table it was permafrost in the area and the fossil ice-wedge in section 4 was formed. The ice in the wedge melted and was filled with sand and gravel before it was covered by sediment gravity flows from the valley sides. The ice-wedge could also have been formed and fossilized, before the stratigraphically overlying till was deposited.

It is also possible, but not likely, that the wedge is of tectonic origin.

8:1:7 Conclusions

It is likely that two glaciers deposited tills and glaciofluvial sediments at Mjälaryd. Some of the uppermost diamicton units were deposited in a subaquatic environment, by sediment gravity flows.

8:2 Hundhult

The site at Hundhult is situated about 4 km south of Tenhult. The site is a small sand pit in a low ridge trending north-south. At the site the ridge bends and runs in a westerly direction.

Sand is dominating in the pit, but silt and gravel beds also occur. In the lower parts of the site diamicton units are found.

The wall in the pit strikes approximately northeast-southwest. The sections are described from bottom to top (Fig. 115).

8:2:1 Description

0,7 m horizontally laminated sand (Sh). Thin beds of stratified silty diamicton (Ds) also occur in the unit.

The rock fragment composition is 52% of Visingsö Group of Rocks 45% of crystalline rocks and 3% of paleozoic limestone.

0,2 m one set of planar-bedded cross-laminated sand (Sh). The laminae are dipping 16° towards 191°.

0,3 m horizontally laminated sand and silt (Fl)

0,5 m yellowish gray sandy gravely diamicton (Dm). Clasts are rounded. The rock fragment composition is 43% Visingsö Group of Rocks 56% crystalline rocks and 1% Paleozoic

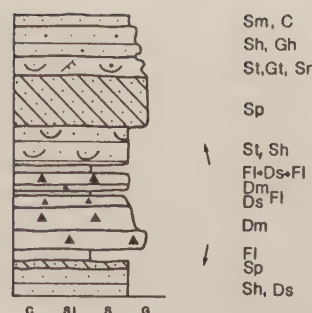


Fig. 115. Log from Hundhult.

limestone.

The unit is very soft.

0,6 m grayish brown gravely sandy diamicton (Dm). Clasts are usually angular. The rock fragment composition is 46% Visingsö Group of Rocks and 54% crystalline rocks. Many weathered clasts of crystalline rocks are observed in the unit.

The unit is consolidated.

0,3 m grayish brown stratified diamicton (Ds). There are lenses of gravel in the unit.

0,1 m Yellow laminated silt with dropstones (Fl).

0,1 m redbrown sandy diamicton (Dm). The rock fragment composition is 47% Visingsö Group of Rocks and 53% crystalline rocks.

0,3 m yellowish brown sandy diamicton (Dm). The rock fragment composition is 38% Visingsö Group of Rocks and 62% of crystalline rocks.

0,03 m laminated silt and fine sand (Fl).

0,02 m stratified sandy diamicton (Ds).

0,1 m laminated silt and fine sand (Fl).

1,0 m trough-bedded cross-laminated sand (St) and horizontally laminated sand (Sh). Thin beds of gravel occur in the lower part of the unit. The unit is a fining upward sequence. The lamination is often disturbed and normal faults are observed in the unit. The cross-lamination dips (one spot) 35° towards 342°.

1,3 m one set of planar-bedded cross-laminated sand and gravel (Sp, Gp). Thin beds of silt occur in the unit. The unit is very contorted.

0,5 m trough-bedded cross-laminated sand and gravel and small-scale cross-laminated sand and silt (St, Gt, Sr).

0,7 m alternately horizontally laminated sand and gravel (Sh, Gh). The rock fragment composition is 47% Visingsö Group of Rocks and 53% crystalline rocks. The lamination in the unit is disturbed and the laminae are dipping 48° towards 354°.

0,3 m massive gravely sand with organic material (Sm, C) (soil).

8:2:2 Discussion

The diamicton units, in the lower parts of the section, are sandy or gravely with rounded clasts. The rock fragment composition in the diamicton units are similar to those of the interbedded glaciofluvial units. This indicates that the diamicton units were deposited by sediment gravity flows, during the deglaciation of the area. The glaciofluvial sediments were deposited by melt water, flowing approximately southwards, probably through the narrow valley south of

the site.

The disturbances and faultings in the upper part of the section indicates that the glaciofluvial sediments were deposited on or were supported by stagnant ice. Beds with only minor disturbances show possible paleocurrent towards the north. Northwest of the site there is an erosional channel, indicating a water transport towards northwest. A possible explanation to this transport direction could be drainage of meltwater from the Tenhultasjön basin east of Hundhult (Fig. 2).

The rock fragment composition of the diamicton units varies between 38-52% Visingsö Group of Rocks with a mean of 45%, which is similar to the upper diamicton unit at Mjälaryd and should therefore be correlated. The rock fragment composition of the glaciofluvial sediments show similarities to the upper gravel at Mjälaryd, but the stratigraphic position of the glaciofluvial sediments at Hundhult and at Mjälaryd are different.

8:2:3 Conclusions

The sediments at Hundhult were deposited with ice-contact. In the lower parts of the section paleocurrent is towards the south and in the upper part towards the north. The diamicton units are probably deposited by sediment gravity flows.

8:3 Uppegården

The section is situated at Uppegården about 500 m north of Häljaryd (Fig. 105). The excavation is a trench for water pipes. The excavation walls are about 2 m high. The highest elevated point of the excavation (+211 m) is the north-eastern end of the trench and the lowest point (+203 m) is in the south-western end of the trench. Six minor sections (1-6) are described from the trench.

8:3:1 Sections

Section 1 is in the south-western end of the trench and section 6 is in the north-eastern end of the trench.

The sections are described from bottom to top (Fig. 116).

Section 1

Section 1 is situated in the south-western end of the trench. The bottom of the section is at about +201 m (Fig. 116).

0.8 m grayish brown sandy diamicton (Dm). The grain-size composition is shown in Fig. 116. Clasts in the bed are rounded or well rounded. The rock fragment composition is 11% Visingsö Group of Rocks and 89% crystalline rocks.

0.3 m massive gray silty clay (Fm).

0.2 m clay gyttja (Fm, C).

0.2 m gyttja (C).

Between section 1 and 2 there is a lens of violet red sandy diamicton with a rock fragment composition of 10% of Visingsö Group of Rocks.

Section 2

Section 2 is situated about 10 m northeast of section 1, the section starts at about +202 m (Fig. 116).

0.2 m massive redbrown sandy diamicton (Dm). The grain-size composition is shown in Fig. 116. The rock fragment composition is 9% Visingsö Group of Rocks and 91% crystalline rocks.

0.5 m massive gray and red clayey sandy diamicton (Dm). The grain-size composition is shown in Fig. 116. The rock fragment composition (two samples) is 18 resp. 12% Visingsö Group of Rocks and 82 resp. 88% crystalline rocks.

0.1 m massive sand (Sm).

0.4 m massive silty clay (Fm). There are clasts of granule and pebbles size in the unit.

0.4 m massive silty clay with organic material (Fm,C).

Section 3

Section 3 is situated about 25 m north-east of section 1. The section starts at about +204m (Fig. 116).

0.5 m massive brownish red sandy diamicton (Dm). The diamicton unit is the best sorted of the sampled units from the site (Fig. 116). The rock fragment composition is 5% Visingsö Group of Rocks and 95% crystalline rocks.

0.8 m red massive sandy diamicton (Dm). The

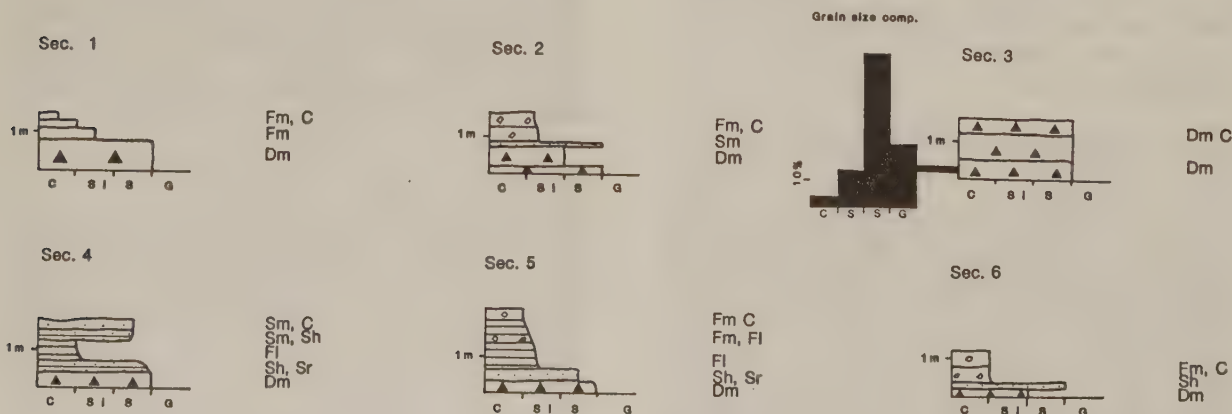


Fig. 116. Log 1-6 from Uppegården.

grain-size composition is shown in Fig. 116. The rock fragment composition is 68% of Visingsö Group of Rocks and 32% crystalline rocks. The lower contact is interbedded.

0.4 m massive sandy diamicton with organic material (C).

Section 4

Section 4 is situated about 10 m north of section 3. The section starts at about the same level as section 3 (+205 m) (Fig 116).

0.4 m red brown massive sandy diamicton (Dm).
0.3 m horizontally and small-scale cross-laminated sand (Sh, Sr).

0.6 m red brown rhythmically laminated silt and clay (Fl). In the lower part of the unit there are beds of horizontally and small-scale cross-laminated sand. At least 72 clay laminae are possible to distinguish in the unit.

0.3 m massive and faintly laminated sand (Sm, Sh).

0.3 m massive sand with organic material (Sm,C)

Section 5

Section 5 is situated about 50 m north-east of section 4. The section starts at about +206 m (Fig. 116).

0.3 m massive red brown sandy diamicton (Dm).
0.3 m horizontally laminated- and small-scale cross-laminated sand (Sh, Sr). There are some gravel and pebble size clasts in the unit.

0.7 m rhythmically laminated silt and clay (Fl). In the lower part of the unit there are some beds of horizontally- and small-scale cross-laminated sand. At least 103 clay laminae are possible to distinguish in the unit (Fig. 117). The clay laminae are usually thicker than the silt laminae (Fig. 117).

0.6 m massive or faintly laminated clay (Fm, Fl).

0.3 m massive clay with organic material (C).

Section 6

Section 6 is situated about 80 m east of section 5. The section starts at about +210 (Fig. 116).

0.2 m massive silty diamicton (Dm). The grain size composition is shown in Fig. 137. The rock fragment composition is 75% Visingsö Group of Rocks and 25% crystalline rocks.

0.2 m horizontally laminated sand (Sh).

0.4 m massive clay (Fm).

0.4 m massive clay with organic material (C).



Fig. 117. The lower part of the varved clay in section 4 at Uppegården.

8:3:2 Discussion

It is surprising to find diamicton in the surface at a lower altitude (about +204 m in section 2) than rhythmically laminated clay (about +206 m) in section 4. The sections are less than 50 m apart.

There are three possible explanations for this topographic discrepancy. 1) The section with diamicton on the top might have been in a more exposed position (to erosion) during the deposition of rhythmically laminated clay and silt and thus no suspended sediments were deposited, 2) stagnant ice covered the diamicton units or 3) the diamicton units were elevated by buried stagnant ice, during the deposition of rhythmically laminated silt and clay.

Section 3 was situated in a somewhat more exposed position than section 5 if water flowed in the center of the valley. The small difference in the distance (20 m) to the central part of the valley should not influence the geological record. In other places in the valley, thick beds of laminated clay and silt were deposited, in the central part of the valley, at levels above +210 m (Svantesson 1985). It is more likely that a big stagnant ice block was lying in the depression between Klevarp and Tenhult during the existence of the glacial lake in which the rhythmically laminated sediments were deposited. Whether the diamicton was on top, within and/or beneath the stagnant ice body is not clear.

The surficial geology, with thin beds of glacial clay (Svantesson 1985) and the depression between Klevarp and Tenhult (Fig. 105), also support the idea of a stagnant ice body in the area, during the deposition of rhythmically laminated silt and clay. Southeast of

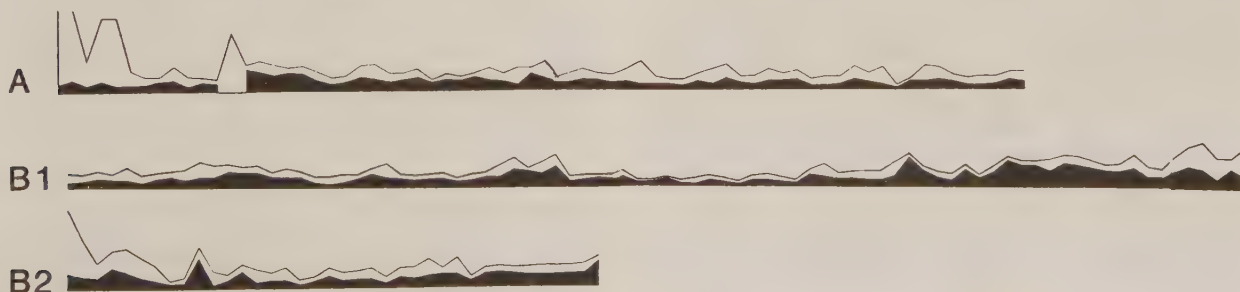


Fig. 118. Graph of the varved clay at A) Uppegården and B1) and B2) Hulugården.

Eket clay was deposited up to +212 m, and from an excavation nearby more than 6 m of clay is reported. It is not likely that clay was deposited at +212 m at Eket, and not at the 12 m lower site at Uppegården 700 m south of Eket.

The sequences of rhythmically laminated silt and clay in section 4 and 5 are probably varved clay. The two sequences are only 50 m apart, but are not possible to correlate (Fig. 118).

The rock fragment composition display two types of diamicton at Uppegården. The uppermost diamicton units have high value of Visingsö Group of Rocks (68 and 85%). The lower diamicton units have only about 10% Visingsö Group of Rocks. The big difference in rock fragment composition might indicate that the diamicton types were deposited by different glaciers.

8:3:3 Conclusions

During the deglaciation of the last glacier in the area around Tenhult stagnant ice-bodies were left in front of the active glacier. Between the thresholds, and the glacier front a glacial lake was dammed. In the glacial lake varved clay was deposited on top of and between the stagnant ice-bodies.

8:4 Hulugården

About 700 m north of Uppegården two small sections were cleaned in a ditch. The sections are close to Hulugården (Fig. 119). The sections are situated about 30 m west of the main road, between Huskvarna and Tenhult. The sections are about 10 m apart (Fig. 119).

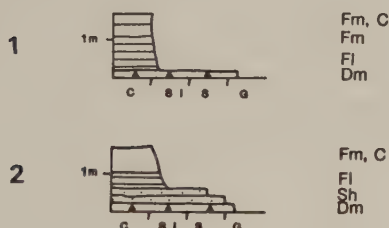


Fig. 119. Log from section 1 and 2 from Hulugården.

8:4:1 Section 1

Section 1 is situated about 30 m west of the main road, between Huskvarna and Tenhult. The section starts at about +204 m (Fig. 119).

0.2 m massive reddish gray gravelly sandy diamicton (Dm). The rock fragment composition is 15% Visingsö Group of Rocks and 85% crystalline rocks.

0.9 m rhythmically laminated silt and clay (Fl). In the lower part of the unit, there are some thin laminae of sand. At least 100 clay laminae are possible to distinguish (Fig. 118).

0.3 m massive or faintly laminated clay (Fm).
0.3 m massive clay with organic material (Fm,C).

8:4:2 Section 2

Section 2 is situated about 10 m east of section 1 and starts at the same level (+204 m). **0.2 m massive reddish gray gravelly sandy diamicton (Dm).** The rock fragment composition is 19% Visingsö Group of Rocks and 81% crystalline rocks.

0.2 m horizontally laminated sand (Sh).

0.15 m horizontally laminated fine sand and silt (Sh).

0.4 m rhythmically laminated silt and clay (Fl). In the lower part of the unit, there are thin beds of sand.

0.7 m massive clay gyttja (Fm, C).

8:4:3 Discussion

The diamicton units in the two sections show similar grain-size and rock fragment composition and are possibly correlated with the lower diamicton units at Mjälaryd and Uppegården.

The units of rhythmically laminated silt and clay are most likely varved clay. The two sequences are only 10 m apart but are not geochronologically possible to correlate. However, the sequence from section 1 has the same configuration as the varve sequence from section 5 at Uppegården (about 700 m to the south (Fig. 118)).

8:5 Klevarp

About 1 km north of Klevarp (Fig. 105) four diamicton samples are collected in deep ditches.

8:5:1 Description

The grain-size composition varies a lot between the samples.

The rock fragment composition varies between 54-81% Visingsö Group of Rocks and 46-19% crystalline rocks.

8:5:2 Discussion

The genesis of the diamicton units are not known but the rock fragment composition indicates the units belong to the upper type of diamicton found at Mjälaryd and Uppegården.

8:6 Tenhult

At the Texaco petrol station at Tenhult, there is an about 2 m deep excavation (Fig. 120).



Fig. 120. Log from Tenhult.

8:6:1 Description

1.5 m muddy gravel (Gm). The clasts are matrix supported, although 70% of the material is coarser than sand. There is about 8% of the clay fraction in the unit. Lumps of

rhythmically laminated clay are observed in the unit. The rock fragment composition is 45% Visingsö Group of Rocks and 55% crystalline rocks.

0.5 m massive clayey gravelly sandy diamicton (Dm). The unit is reddish brown with thin winding veins of light gray clay or clayey diamicton. The rock fragment composition is 25% Visingsö Group of Rocks.

0.25 m massive grayish brown clay (Fm).

8:6:2 Discussion

The described section is in the south-eastern end of a north-west--south-east trending ridge. The ridge starts at the mouth of the trench-like valley, connecting lake Tenhultasjön with the Tenhult valley (Fig. 105). The ridge is about 500 m long and 200m wide. The ridge damms up a peat bog to the south-west. The ground water table is about 10 m higher on the south-western side of the ridge, than on the north-eastern side.

The clasts in the lower unit of muddy gravel are not in contact with each other, indicating that the fines were deposited at the same time as the clasts. Most likely the whole unit is deposited at the same time.

The rock fragment composition of the lower muddy gravel is about the same as the surficial diamicton units in the area, and similar to that of the upper diamicton unit at Mjälaryd (Fig. 107). The superimposed diamicton unit has a rock fragment composition, similar to that of the lower units at Mjälaryd and Uppegården. The stratigraphy is inversed compared with those sites.

There are two possible ways that a ridge with a stratigraphy like this could have been formed. The ridge is either a frontal morainic ridge or the ridge was formed by a catastrophic drainage of lake Tenhultasjön to the Tenhult valley. In the second alternative the ridge was deposited with ice contact. In the first alternative the sediments were deposited by slides, slumps and/or debris flows in shallow water (the site is below +220) from the glacier front and/or the valley slopes. In the second alternative the muddy gravel is a drainage sediment.

In the small section it is not possible to find out the genesis of the upper diamicton unit. It was either 1) formed by debris flows from the glacier front or the valley slopes or 2) the diamicton is a till formed under the glacier. 1) The diamicton in the valley slopes, and the higher areas surrounding the Tenhult valley has a rock fragment composition with less than 20% of Visingsö Group of Rocks, which might explain the low Visingsö Group of Rocks frequency in the upper diamicton at Tenhult.

2) At Mjälaryd, the lowest part of the upper diamicton is interpreted as a till. The rock fragment composition of this till is about 60% Visingsö Group of Rocks. It is not likely that a glacier advance will deposit a "new" till, with a completely different rock fragment composition, only at this place, and not in the other sites in the vicinity.

The uppermost thin unit of clay was deposited in a glacial lake stage after the deglaciation of the area.

8:6:3 Conclusions

The lower unit of muddy gravel was most

likely deposited by a catastrophic drainage of lake Tenhultasjön. The overlying diamicton unit was probably formed by debris flows, derived from somewhere outside the valley. The uppermost unit of clay is deposited in a glacial lake that existed between the deglaciation and the drainage of the Vättern basin eastwards.

8:7 Bråneryd

About 500 m south of Bråneryd (Fig. 105) there is a sand and gravel pit. The bottom of the pit is at about +136 m. The described section is a compilation of the total stratigraphy of the site. Different parts of the pit were exposed at different times (Fig. 121). The stratigraphy is described from bottom to top (Fig. 121).

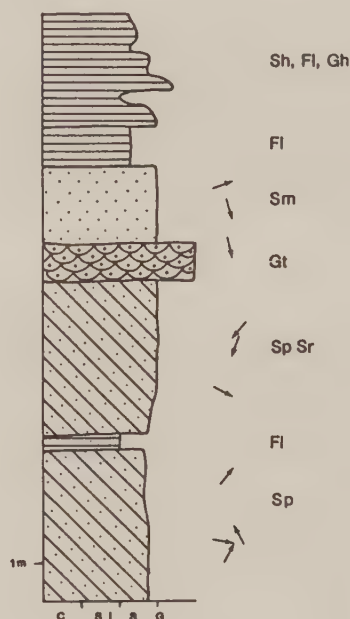


Fig. 121. Log from Bråneryd.

8:7:1 Description

4 m of one set of planar-bedded cross-laminated sand (Sp). Clasts, of silt and rhythmically laminated clay, are commonly found in the unit.

The rock fragment composition of the unit is 61% Visingsö Group of Rocks and 39% crystalline rocks.

The lamination in the unit is often diffuse. About 1.5 m up in the unit the laminae dip 9° towards 26° and at another spot at the same level 10° towards 101°. About 2 m up in the unit, the laminae dip 16° towards 332° and 3.5 m above the bottom of the pit, the laminae dip 18° towards 39°.

0.4 m laminated silt (FI). The lamination is disturbed by normal faults. The upper and lower contacts are conformable.

4 m one set of planar-bedded cross-laminated sand (Sp) with small-scale cross-laminated sand (Sr). Clasts of silt are found in the unit.

The cross-lamination in the ripples are mostly dipping in the opposite direction to

the laminae in the bar. Sometimes the laminae in the bar is laterally converted into small-scale cross-lamination.

The unit is cut by a number of normal faults. The fault planes are usually in high angle (around 80°) and trend 135-315°. About 1 m up in the unit, the laminae are dipping 35° towards 118°, 2 m up 32° towards 197° and 2.5 m up in the unit 38° towards 221°. The upper contact is erosive.

1.0 m massive and trough-bedded cross-laminated pebbly gravel (Gt). Clasts of silt and rhythmically laminated clay are found in the unit.

Clasts are imbricated towards the north and the laminae in the troughs dip 26° towards 170°.

The rock fragment composition is 79% Visingsö Group of Rocks and 21% crystalline rocks.

2.0 m trough-bedded cross-laminated sand (St). In the lower part of the unit the laminae are dipping 24° towards 164° and in the upper part, 26° towards 71°.

1.0 m laminated fine sand and silt (Fl). The stratification is disturbed by water escape structures. The laminae in the upper part of the unit dip 16° towards 204°.

3.0 m horizontally laminated sand, silt and gravel (Sh, Fl, Gh). The stratification is very contorted.

8:7:2 Discussion

The units of planar-bedded cross-laminated sand have a grain-size composition with a coarse tail, the grain size distribution curve has a negative skewness. The sediment in the unit was deposited by a paleocurrent directed towards a northern sector. The coarse tail suggests that the sediments were not deposited by a glaciofluvial stream but that the unit might be a reworked sediment, a littoral or a fluvial deposit. The unit was deposited up to about +140 m. If the glacier front was south of the Östergötland plain the water level in the Vättern basin was above +200 m. If the glacier front was north of the plain the water level was at about +100 m. This indicates that if the unit is not of glaciofluvial origin it was deposited during an intermediate stage, probably during the damming of the threshold over the Östergötland plains. If the unit is a littoral deposit a glacier cannot have been south of the Östergötland plain.

The unit of silt indicates a short period of low energy water.

The superimposing unit of planar-bedded cross-laminated sand and the unit of pebbly gravel display a consistent paleocurrent towards the south. The coarsening upwards indicates a more proximal position to the conduit transporting the sediments.

A paleocurrent towards the south provides a glacier close to the deposit. If a glacier was close the sediments were deposited in a glacial lake with a water level of about +220 m, suggesting the sediments were deposited on the bottom of an about 60 m deep glacial lake. It is possible that the silt layer, the planar-bedded cross-laminated sand and the massive and trough-bedded pebbly gravel is a complete delta sequence, with bottomset-, foreset- and topset beds. The topset bed in a delta is usually subaerially deposited but this time it was subaquatically aggraded in a cavity close to the conduit, in the glacier

or deposited by a jetstream in front of the glacier.

The slabs or intraclasts of silt and clay, indicate erosion of the substratum of the valley. This indicates that the water transporting the sediments was flowing in a subglacial tunnel and not on the glacier surface.

Over the delta sequence, there is a fining upwards sequence, indicating a more distal position to the meltwater source.

The uppermost unit of contorted sand, silt and gravel could have been deposited by sediment gravity flow from the glacier front and/or the surrounding slopes.

The normal faults in the lower units, indicate that the sediments are deposited with ice-support.

8:7:3 Conclusions

The lowest unit of planar-bedded cross-laminated sand was deposited in low energy shallow water. The paleocurrents were directed towards a northern sector. This indicates that the unit was deposited, neither when the glacier in the Vättern basin was north of the Östergötland plain, nor when it was south of it, but during an intermediate stage.

The overlying delta sequence was deposited at the bottom of an approximately 60 m deep ice-lake, probably close to the glacier front. The material supplying stream was transported in a subglacial conduit.

The fine-grained sediments superimposing the delta sequence was deposited in low energy water, when the glacier retreated or when the tunnel entrance was shifted.

The uppermost unit was deposited by sediment gravity flows from the glacier front and/or from the surrounding areas.

8:8 Viktoriaplan

The site is situated in Huskvarna (the northernmost end of the Tenhult valley, (Fig. 105). The site is in the steep westfacing slopes. The section is an approximately 8 m high excavation wall. The bottom of the excavation is at about +140 m. The section is described from bottom to top (Fig. 122).

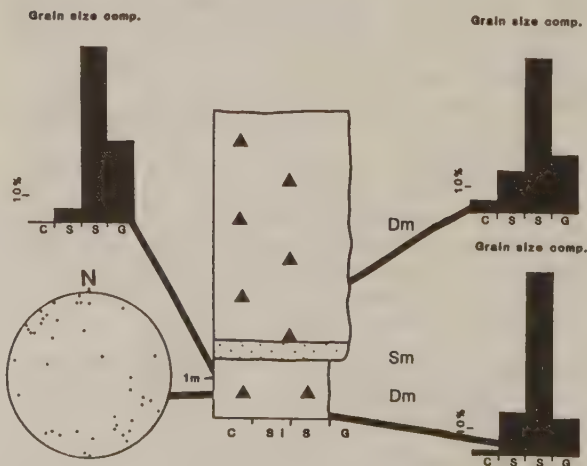


Fig. 122. Log from Viktoriaplan

8:8:1 Description

1,5 m massive yellow brown sandy diamicton (Dm). The diamicton is very consolidated. The rock fragment composition is 50% Visingsö Group of Rocks and 50% crystalline rocks. In the middle of the unit a fabric analysis was made (Fig. 122). The upper contact is sharp.

0,5 m massive gravely sand (Sm). The sediment is poorly sorted and many big clasts occur in the unit. Clasts are usually angular. The rock fragment composition is 43% Visingsö Group of Rocks, 56,5% crystalline rocks and 0,5 % Paleozoic limestone. The upper contact is conformable.

6,0 m massive brown gravely sandy diamicton (Dm). The rock fragment composition of the unit is 64% Visingsö Group of Rocks and 36% crystalline rocks.

8:8:2 Discussion

The site is situated in a steep slope facing west.

The fabric of the lower unit displays two clusters of clasts long axes. One is around 150° and the other is around 315° . This indicates a direction of shear during or after the deposition in a northwest-southeasterly direction (in this case, the direction of shear was most likely from north west). The direction of shear is perpendicular to the direction of the slope, which indicates that the unit was not deposited by debris flows from the surrounding slopes. Debris flows from the glacier front are not likely because the glacier terminated in deep water. This argument suggests that the unit was deposited below the glacier, either as a lodgement till or as a meltout till. The unit can, of course, also be a deformed sediment.

The overlying unit of poorly sorted sand displays a coarse tail on the grain-size composition. The clasts show high angularity and the rock fragment composition is about the same as the underlying unit. These arguments suggest that the unit is a washed normal diamicton or a surficial diamicton (Boulton and Deynoux 1981).

The rock fragment composition of the upper diamicton shows a higher amount of Visingsö Group of Rocks than the underlying units, indicating that "new" material was introduced. This "new" material came either from higher parts of the glacier which deposited underlying units alternatively the sediment was brought by another glacier. The genesis of underlying unit suggests the second alternative.

8:9 Trollberget

The site is a sand pit about 1,0 km south west of Bråneryd (Fig. 105).

The bottom of the pit is at about +175 m. The stratigraphy is a compilation of some sections open, at different times (Fig. 123).

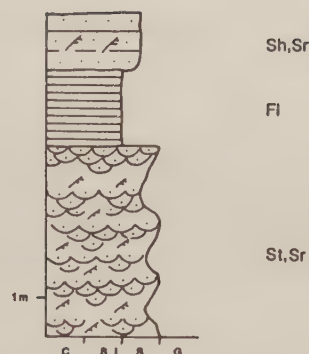


Fig. 123. Log from Trollberget.

8:9:1 Description

5 m trough-bedded cross-laminated and small-scale cross-laminated sand (St, Sr). The unit is fining upwards. The laminae in the trough dip towards the south-east (a mean out of six measurements, Fig. 123). The upper contact is conformable.

0,5-2,0 m laminated silt (Fl).

0,5-1,5 m horizontally and small-scale cross-laminated fine sand (Sh, Sr).

8:9:2 Discussion

The paleocurrent of the lower unit indicates glaciofluvial deposition. The topographic position suggests deposition from a lateral stream. The fining upward sequence indicates a successively more distal position to the mouth of the meltwater stream or a rising of the water level.

The uppermost sand unit, might be a littoral deposit formed during the drop of the water-level as the deglaciation proceeded.

8:10 Bäckamarken

About 1,2 km south of Trollberget (Fig. 105) there is a rather long section. The bottom of the section is at about +200 m. The section is about 3 m high.

8:10:1 Description

3 m trough-bedded cross-laminated sand (St). Thin beds of silt were found in the unit. The laminae in the trough dip towards an eastern sector.

8:10:2 Discussion

The unit was deposited by flowing water with a paleocurrent towards the east.

9 Sites on the slopes of the Tabergsån valley

This area also includes the Lillån valley. The sites are all found on the slopes of the Tabergsån valley (Fig. 124). Ravines and other erosional morphology dominate in this area. Under +220 m, the Quaternary sediments in the area are totally dominated by water

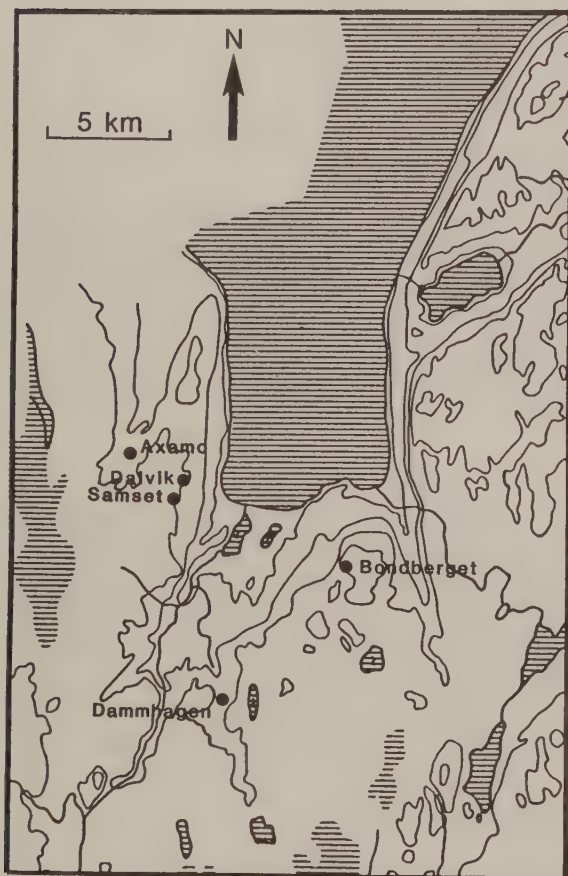


Fig. 124. Sites in the Tabergsån valley.

sorted sediments.

The sites in this subarea vary in altitude between +170 and +250m.

Today, two small streams (Tabergsån and Lillån) are flowing northwards in the area. Both streams start close to the main water divide at an altitude of about + 220 m.

9:1 Bondberget

The site is at the top of the skiing pist at Bondberget (Fig. 124). The bottom of the section is at about +220 m (Fig. 125).

9:1:1 Description

0,5 m massive gray silty sandy diamicton (Dm). The diamicton is consolidated and jointed. The rock fragment composition is 81% Visingsö Group of Rocks and 19% crystalline

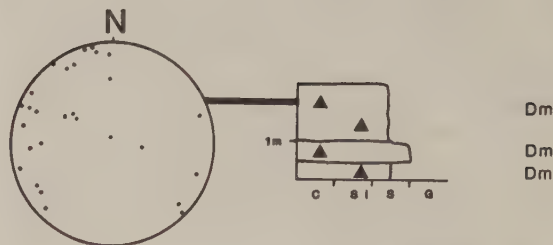


Fig. 125. Log from Bondberget.

rocks. The upper contact is conformable.

0,5 m massive redbrown sandy diamicton (Dm). The unit is unconsolidated. A fabric analysis was made in the unit. The rock fragment composition is 59 resp. 67% Visingsö Group of Rocks and 41 resp. 33% crystalline rocks.

1,5 m massive reddish brown and light gray spotted diamicton (Dm). The unit is unconsolidated. A fabric analysis is made in the unit. The rock fragment composition is 51 resp. 70% Visingsö Group of Rocks and 49 resp. 30% crystalline rocks.

9:1:2 Discussion

The section is situated at the top of a rather steep slope.

The grain-size and rock fragment composition suggest a different origin of the lower diamicton unit, compared with the overlying units.

The fabric analyses display a weak cluster of particle long axes around 300° (Fig. 125). This direction is also the trend of the slope, and the direction of the striae in the area (Fig. 24).

The rock fragment- and grain size composition of the lower unit, is similar to the Rosenlund diamicton, and the rock fragment and grain size composition of the upper two units are similar to the Öxnehaga diamicton.

9:2 Dalvik

At Dalvik about 2 km west of the center of Jönköping (Fig. 124) there is an approximately 2,5 m high excavation. In the central part of the excavation, the crystalline bedrock is exposed. The exposed cliff has a whale-back, form is glacially polished and shows many striae (Fig. 126). The stoss side of the cliff is facing towards the south east. The direction of the striae varies between $100-280^{\circ}$ and $130-310^{\circ}$ (Fig. 24). The section is described from bottom to top (Fig. 127).

9:2:1 Description

0,2 m deformed gravely sand (Sd). There are many pebbles in the unit.

0,7 m massive redbrown and light gray spotted gravely sandy diamicton (Dm). The unit is heterogeneous with many lenses of sorted sediments. Most clasts are rounded. The rock



Fig. 126. The bedrock knob at Dalvik. The picture was taken towards the northwest.

fragment composition is 49% Visingsö Group of Rocks and 51% crystalline rocks.

The bed tapers towards the bedrock knob. The upper contact is loaded.

0,05-0,45 m deformed laminated sand (Sd). The unit is folded and tapers towards the bedrock knob.

1,0 m massive redbrown sandy silty diamicton (Dm). There are many light gray winding veins in the unit. There are many weathered clasts in the unit. Smaller clasts are often stacked into clusters, sometimes without matrix between the clasts.

A fabric analysis was made about 0,1 m above the surface of the bedrock knob (Fig. 127).

0,4 m massive diamicton with organic material (Dm,C).

9:2:2 Discussion

The whale-back form of the bedrock knob and the striae indicate an ice-movement towards a western sector. The fabric analyses display two clusters of particles long axes (Fig. 127). The strongest cluster is at about 41° and the other at about 137° . There is about 90° between the two groups.

The striae in the bedrock just below the upper diamicton, where the fabric analysis was made, were probably eroded by the same glacier. If this was the case, the depositing glacier moved in a north westerly direction, which is uphill. A glacier moving uphill is moving under compressive flow. According to Boulton (1971), clasts long axes tend to have a transverse (to the ice-movement) maximum in a glacier flowing with compressive flow. The rock fragment composition indicates that the diamicton units were deposited by the same glacier.

Boulton (1978) uses stacking of clast as a strong criterium for lodgement till.

9:2:3 Conclusions

The last ice-movement over the area was probably towards the northwest or west. The upper diamicton unit might be a lodgement till.

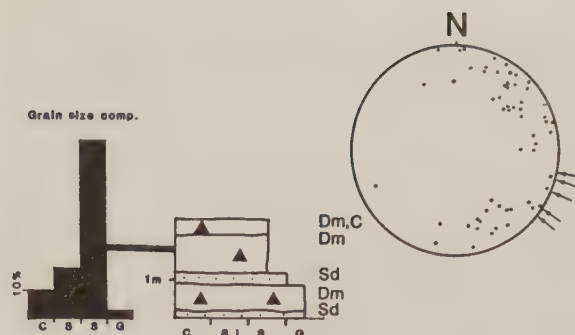


Fig. 127. Log from Dalvik.

9:3 Samset

About 2 km east of Samset, about 2 km west of the center of Jönköping (Fig. 124) a road cut is cleaned and described. The section is situated in a depression in the crystalline bedrock and strikes $150-330^{\circ}$. The section starts at about +200 m (Fig. 128).

9:3:1 Description

0-0,5 m massive grayish brown sandy silty diamicton (Dm). The clay content is about 10%. The unit is very consolidated and contains many weathered clasts. Contorted sand-lenses occur in the unit. The unit forms a mound in the section. The rock fragment composition is 60% Visingsö Group of Rocks and 40% crystalline rocks.

0,05 m horizontally laminated coarse silt (Fl). The unit is deformed and tapers towards the underlying mound of diamicton.

0-0,4 m massive bluish gray sandy silty diamicton grading into faintly stratified diamicton (Dm--FDs). The clay content is about 10%. The unit is contorted and tapers towards the mound of the underlying diamicton unit. The unit is jointed and has iron and manganese oxides precipitated in the fractures. The rock fragment composition is 57% Visingsö Group of Rocks and 43% crystalline rocks.

The upper contact is loaded.

0,1 m laminated bluish gray silt with thin beds of clay (Fl). The stratification is deformed. The unit tapers towards the underlying mound of diamicton.

0,5 m laminated yellow coarse silt with thin beds of red clay (Fl). The sediment becomes more homogeneous upwards. The unit is bent over the underlying mound of diamicton. The upper and lower contact is conformable.

0,4 m massive reddish brown sandy silty diamicton (Dm). The clay content is about 10%. The unit is spotted in light gray. The rock fragment composition is 58% Visingsö Group of Rocks and 42% crystalline rocks.



Fig. 128. Log from Samset.

0,2 m horizontally laminated fine sand (Sh). The unit is contorted and can laterally be traced to an overlying unit of laminated fine sand.

0,4 m massive redbrown clayey silty diamicton (Dm). The unit is spotted in light gray. The unit has a heterogeneous grain-size composition. The clay content is higher in the lower parts of the unit. The unit seems to be a slab in the laminated fine sand. The rock fragment composition is 60% Visingsö Group of Rocks and 40% crystalline rocks.

0,6 m horizontally and trough-bedded cross-laminated fine sand (Sh,St). The unit is contorted. The unit increases in thickness towards the southeast. The laminae in the troughs dip towards the northwest.

9:3:2 Discussion

The rock fragment composition of the lowest unit is about the same as in the other diamicton units in the vicinity, and in the section. The mound-form of the unit was most likely formed before overlying units were deposited.

The bed of laminated bluish gray silt was deposited in a subaquatic environment. It is also likely that the underlying unit of massive and stratified diamicton is a subaqueous deposit. The succession from massive to stratified diamicton indicates that the unit is deposited by sediment gravity flow processes, probably debris flows.

Over the bluish gray silt there is a unit of laminated coarse silt. This coarsening upwards indicates a possible shallowing of the pond, in which underlying sediments were deposited, or that the sediment was deposited in a more proximal position to the glacier.

The genesis of the redbrown sandy silty diamicton is obvious, but the change from silt and clay, deposited in a glaciolacustrine environment, to a massive diamicton indicates that a glacier passed

over the area alternatively that the glacier front was close to the site.

The paleocurrent towards the northwest in the upper sand unit indicates that the glacier front was east of and very close to the site. The slab of diamicton in the sand also confirms this. The slab is probably a debris flow from the nearby glacier front.

9:3:3 Conclusions

The stratigraphy of the site suggests that the glacier front oscillated over the area of the site. In the icefree periods the area was covered by glacial lakes in which glaciolacustrine sediments were deposited. During the last deglaciation the meltwater was flowing in a northwesterly direction, probably to the thresholds at Olsbo (Fig. 2) and further, to the Nissan valley.

9:4 Axamo

About 600 m east of Axamo there is a big sand and gravel pit (Fig. 124). The bottom of the pit is at about +215 m. The excavation wall is about 500 m long and strikes 75-255°.

Northwest of the site, there is a large area with deep water eroded ravines. The trenches in the area are up to 3 m deep. The sediments in the area consist of horizontally- and small-scale cross-laminated fine sand and silt.

The gross stratigraphy and representative section from the western part of the pit is described below.

9:4:1 Gross description

The lower parts of the excavation wall consist of planar-bedded cross-laminated sand (Fig. 129,130), with interbedded regressive ripples, mainly type B (Jopling and Walker, 1968). The thickness of the unit varies and



Fig. 129. The upper part of the section at Axamo.

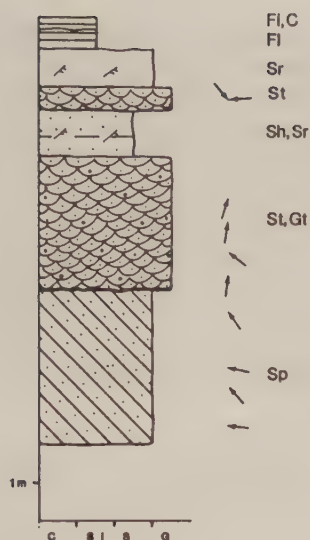


Fig. 130. Log from Axamo.

is in some place possible to trace almost to the top of the section. The upper contact is eroded by fluvial action.

Channels, filled with trough-bedded cross-laminated sand and gravel are cut into the underlying unit of planar-bedded cross-laminated sand.

These two units are covered by horizontally and small-scale cross-laminated silt and fine sand. This unit is about 1 m thick.

The silt and fine sand is superimposed by an approximately 1,5 m thick unit of trough-bedded cross-laminated sand and small-scale cross-laminated sand.

At the top of the excavation there is an approximately 0,5 m thick unit of rhythmically laminated silt and clay (Fig. 130).

9:4:2 Description of section

2,0 m scree.

4,0 m planar-bedded cross-laminated with interbedded small-scale cross-laminated sand (Sp, Sr). Thin beds of laminated silt occur in the unit. The cross-lamination of the ripples and the bar has opposite directions. Both type-A ripples and B ripples are found in the unit.

The thin beds of silt diminish upwards and the unit shows an overall coarsening upwards. In the bottom of the unit the laminae are dipping 11° towards 273° , about 1,5 m up in the unit, 9° towards 318° , about 2 m up 13° towards 280° and about 3,5 m up 22° towards 325° .

The upper contact is erosive.

3,5 m trough-bedded cross-laminated sand and gravel (St, Gt). About 0,4 m up in the unit the laminae in a trough dip 22° towards 6° , about 1,0 m up 31° towards 306° , about 1,8 m up 9° towards 2° and 2,4 m up in the unit 24° towards 16° . The upper contact is conformable.

1,2 m horizontally and small-scale cross-laminated fine sand and silt (Sh, Sr). The small-scale cross-laminated sediments consist of type-B and sinusoidal ripples. The upper contact is conformable.

0,6 m trough-bedded cross-laminated sand and

gravel (St, Gt). About 0,4 m up in the unit, the laminae in a trough dip 26° towards 141° . At the same level, but about 30 m to the west, the laminae in a trough dip 30° towards 253° . The upper contact is conformable.

1,0 m small-scale cross-laminated sand (Sr). There are only type-A ripples in the unit. Many of the ripples are close to the upper limits of size. The direction of the dip of the foreset laminae in the ripples is varied throughout the unit. The upper contact is conformable.

0,5 m rhythmically laminated sand and clay (Fl). The clay laminae are usually very thin. 0,3 m laminated silt and clay with organic material (Fl, C (soil)).

9:4:3 Discussion

The sand and gravel pit shows a delta sequence. The planar-bedded cross-laminated sand is the foreset bed. The unit was deposited by a glaciofluvial stream, flowing towards the west-north-west.

The overlying unit of trough-bedded cross-laminated sand and gravel was deposited in the main channel which transported sediment and water into a low energy water. The paleocurrents in the channel are towards a northern sector.

The superimposed unit of horizontally laminated and small-scale cross-laminated sand and silt is probably deposited during a shift of the main channel, perhaps due to aggradation of sand and gravel on the bottom of the channel.

The overlying unit of trough-bedded- and small-scale cross-laminated sand indicates a new episode of deposition in an active channel. This time the stream was not as steady as when the underlying channel sediments were deposited. Perhaps the channel at this time was of a second order, and only used when there was extremely high water transport in the braided stream. Another possibility is, that the site at this time was in a distal position to the glacier and thus distal to the source of material.

The uppermost unit of rhythmically laminated silt and clay indicates deposition in low energy water. The glacial lake must have had a waterlevel of at least +230 m.

The sediments in the area, with the deep ravines north west of the sand and gravel pit, are probably the bottomset bed of the delta.

The deposit described is a delta, aggraded in a glacial lake with a waterlevel of more than +230 m. The materialsupplying stream was flowing in a westerly or northwesterly direction. This direction means that the water was flowing against the topography (Fig. 124), indicating that an active glacier front was close, when the sediments were deposited. The fine-grained sediments were deposited up to about +230 m. This is the same level as the thresholds westwards to the Nissan valley at Olsbo, and it is about 10 m higher than the cols southwards at Taberg, Barnarp and Tenhult. The threshold at Olsbo is situated about 15 km north of the thresholds towards the south, but with a gradient of the isostatic uplift of the same order as when the Vättern basin was in contact with the Baltic Ice Lake (Norrman 1964, 1979). The cols were at about the same

level at the time of deglaciation of the area.

9:4:4 Conclusions

The section at Axamo displays a delta sequence deposited in a glacial lake with a waterlevel of about +230 m. The sediments were deposited by a glaciofluvial stream, flowing in a northwesterly direction. The glacial lake was probably drained westwards through the col at Olsbo towards the Nissadalen valley (Fig. 2).

9:5 Damnhagen

About 1 km south of the church in Barnarp there is a big sand and gravel pit (Fig. 124). The bottom of the pit is at about +168 m. In the lowest part of the pit, a drilling was made down to a supposed bedrock at an al-

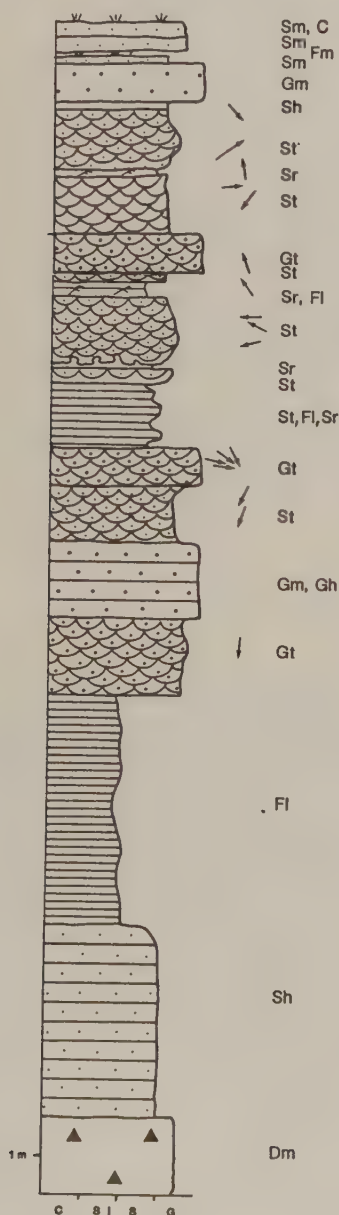


Fig. 131. Log of section 1 at Damnhagen.

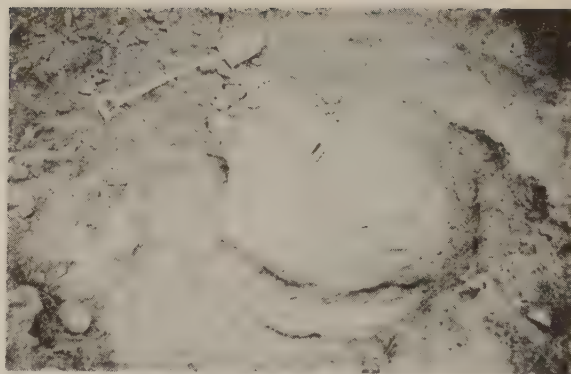


Fig. 132. The eroded silt on the lower part of section 1 at Damnhagen.

titude of about +155 m. The highest point in the pit is about +206 m. The drilling record, which is an extension of section 1, is first described, and then the section is described.

9:5:1 Description of section 1

Section 1 is situated in the western part of the pit. A drilling extends the section. The description of the drilling starts at about +155 m and the section starts at about +168 m. The drilling and the section is described from bottom to top (Fig. 131).

2 m sandy gravely diamicton (Dm). The rock fragment composition is 4% Visingsö Group of Rocks and 96% crystalline rocks (Svantesson 1985)

5 m laminated sand (Sh).

6 m rhythmically laminated silt with thin beds of clay (Fl). The upper contact is erosive (Fig. 132).

Beginning of the section.

2,0 m trough-bedded cross-laminated sandy gravel (Gt). Clasts of laminated sand and silt were found in the unit. The intraclasts are usually armored with well rounded gravel-size particles (Fig. 133).

The dip of the laminae in the troughs are measured at several spots (Fig. 131). The mean direction of the dip is 185° and the mean dip is 17° . The rock fragment composition is 50% Visingsö Group of Rocks and 50% crystalline rocks.

2,0 m massive and horizontally laminated pebbly gravel (Gm, Gh). Clasts are imbricated towards the north. The rock fragment composition is 50% Visingsö Group of Rocks, 49% crystalline rocks and 1% Paleozoic limestone.

1,5 m trough-bedded cross-laminated gravely sand (St). Pebbles are often found in the unit. Close to the upper contact there are some intraclasts. In one of the intraclasts the lamination is disturbed. The intraclast is partly armored. The laminae in the trough are dipping 22° towards 198° and 11° towards 208° .

1,0 m trough-bedded cross-laminated pebbly gravel (Gt). The laminae in three troughs dip 36° towards 157° , 21° towards 125° , 6° towards 96° resp. 10° towards 102° .



Fig. 133. Intraclasts of laminated sediments in the lower part of section 1 at Dammhagen.

0,2 m small scale cross-laminated silty sand (Sr). The bedding plane dips 2° towards 125° .
 0,15 m trough-bedded cross-laminated sand (St).
 0,15 m small-scale cross-laminated fine sand (Sr).
 0,2 m trough-bedded cross-laminated sand (St).
 0,01 m laminated silt (Fl).
 0,1 m trough-bedded cross-laminated sand (St).
 0,02 m laminated silt (Fl).
 0,1 m trough-bedded cross-laminated sand (St).
 0,02 m laminated silt (Fl). The bedding plane is dipping 10° towards 280° . The unit can laterally be traced into an underlying unit of silt.
 0,1 m trough-bedded cross-laminated sand (St).
 0,02 m laminated silt (Fl).
 0,2 m cross-bedded cross-laminated sand (St).
 0,1 m small-scale cross-laminated sand with thin beds of draped laminated silt (Sr, Fl). Sinusoidal ripples are dominating in the unit.
 0,4 m trough-bedded cross-laminated sand (St). The unit is coarsening upwards.
 0,1 m small-scale cross-laminated fine sand with thin beds of draped laminated silt. The bedding plane is dipping 12° towards 297° . Laterally the unit splits up into two units, separated by a unit of trough-bedded cross-laminated sand.
 0,2 m trough-bedded cross-laminated sand (St).
 0,4 m trough-bedded cross-laminated gravelly sand (St). The sand is coarse. The laminae in a trough dip 17° towards 257° . The lower contact is loaded.
 1,2 m trough-bedded cross-laminated sand (St). The dips of the laminae in three

troughs are 19° towards 300° , 17° towards 272° and 11° towards 266° .

0,15 m small-scale cross-laminated sand (Sr).
 0,1 m draped laminated fine sand and silt (Fl).

0,15 m small-scale cross-laminated fine sand (Sr).

0,2 m trough-bedded cross-laminated sand (St). The laminae in one trough are dipping 28° towards 331° .

1,0 m trough-bedded cross-laminated sandy gravel (Gt). Intraclasts of laminated fine sand and silt are found in the unit. The intraclasts are armored by gravel-size clasts. Weathered clasts are common in the unit. The laminae in one trough are dipping 18° towards 340° .

1,6 m trough-bedded cross-laminated sand (St). Thin beds of silt are found in the unit, which is coarsening upwards. About 0,7 m up in the unit the laminae in one trough dip 35° towards 219° . About 1,4 m up in the unit the laminae in a trough dip 22° towards 83° .

0,2 m small-scale cross-laminated sand (Sr). There are mainly type A ripples in the unit.

0,2 m trough-bedded cross-laminated sand (St). The laminae in one trough dip 28° towards 348° .

0,7 m trough-bedded cross-laminated gravelly sand (St). The unit is fining upwards. About 0,2 m up in the unit the laminae in a trough dip 14° towards 54° .

0,7 m trough-bedded cross-laminated coarse sand (St). The laminae in one trough dip 34° towards 141° .

0,1 m horizontally laminated coarse sand (Sh). The bedding plane is dipping 7° towards 357° .

1,0 m massive sandy pebbly gravel (Gm). The unit is poorly sorted.

0,2 m massive sand (Sm).

0,1 m massive silt (Fm). The unit is poorly sorted and contains many dropstones. The rock fragment composition is 46% Visingsö Group of Rocks and 54% crystalline rocks.
 0,4 m massive gravely sand (Sm).
 0,4 m massive sand with organic material (Sm,C).

9:5:2 Section 2

Section 2 is situated in the central part of the pit, about 100 m east of section 1. Section 2 starts at about +173 m, which is about 5 m higher than the bottom of section 1 (Fig. 134).

0,3 m laminated silt with thin beds of clay (F1). The beds of silt are about 0,1 m thick and the clay beds are about 0,01 m thick. The laminae in the unit dip 31° towards 22° (Fig. 135). The upper contact is eroded.

3,0 m trough-bedded cross-laminated sandy gravel (Gt). About 2 m up in the unit, the laminae in three troughs dip 12° towards 34°, 24° towards 172° resp. 5° towards 263°.

2,5 m trough-bedded pebbly gravel (Gt). In the middle of the unit the laminae in two troughs dip 20° towards 52° resp. 28° towards 130°.

1,4 m scree.

0,7 m trough-bedded cross-laminated sandy gravel (Gt). The laminae in two troughs dip 15° towards 271° resp. 11° towards 340°. The unit is dipping 12° towards 327°.

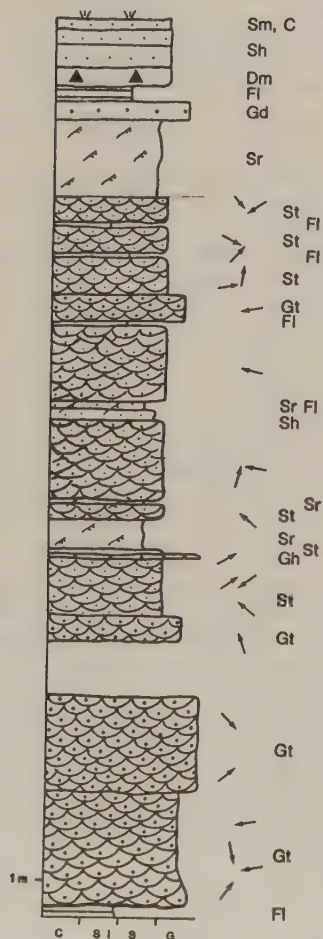


Fig. 134. Log of section 2 at Dammhagen.



Fig. 135. The laminated silt in the lower part of section 2 at Dammhagen.

1,5 m trough-bedded cross-laminated sand (St). The laminae in three troughs dip 17° towards 308°, 11° towards 36° resp. 22° towards 232°.

0,01 m horizontally laminated gravel (Gh).

0,1 m trough-bedded cross-laminated coarse sand (St). The laminae in one trough dip 21° towards 63°.

0,9 m small-scale cross-laminated sand and coarse silt (Sr). The silt is usually found in thin beds, draped over sinusoidal ripples. The silt beds are sometimes deformed by water-escape structures.

0,4 m trough-bedded cross-laminated sand (St). The laminae in a trough dip 14° towards 314°.

0,1 m small-scale cross-laminated sand (Sr).

2,1 m trough-bedded cross-laminated sand (St). The unit is coarsening upwards. About 1,0 m up in the unit the laminae in a trough dip 19° towards 280° and about 1,3 m up the laminae in a trough dip 17° towards 15°.

0,3 m horizontally laminated sand (Sh). In the lower part of the unit there are some thin beds of silt. The unit is dipping 18° towards 285°.

0,01 m laminated clay (Fl).

0,1 m small-scale cross-laminated fine sand and coarse silt (Sr). 2,0 m trough-bedded cross-laminated sand (St). In the middle of the unit the laminae in one trough dip 13° towards 284°.

0,1 m laminated silt (Fl). The unit tapers towards the east. Load-structures are common in the unit.

0,7 m trough-bedded cross-laminated sandy gravel (Gt). The laminae in a trough dip 25° towards 261°. The rock fragment composition is 45% Visingsö Group of Rocks, 54% crystalline rocks and 1% Paleozoic limestone.

1,0 m trough-bedded cross-laminated sand (St). About 0,4 m up in the unit the laminae in one trough dip 12° towards 80° and 0,8 m up in the unit, 16° towards 0°.

0,1 m laminated silt (Fl). There are thin beds of poorly sorted gravel in the unit. Load-structures are common in the unit. The unit is dipping 4° towards 73°.

0,7 m trough-bedded cross-laminated sand (St). The laminae in two troughs dip 24° towards 42° resp. 32° towards 119°.

0,1 m laminated silt and clay (Fl). The unit is draped over underlying unit.

0,7 m trough-bedded cross-laminated sand (St). About 0,3 m up in the unit the laminae

0,2 m laminated silt (Fl). The stratification is contorted.
 0,6 m trough-bedded cross-laminated sand (St). The stratification is contorted.
 0,4 m massive gravel (Gm).
 Scree

9:5:4 Discussion

The lowest unit at Damnhagen is a gravely sandy diamicton, only found in the drilling under section 1. This unit has an extremely high content of crystalline rocks, which most likely was derived from the local bedrock. If the sediment was derived from the local bedrock the unit is probably a till.

The diamicton is superimposed by laminated sand, which is overlain by laminated silt and clay. This fining upward sequence was likely formed after a deglaciation in a narrow glacier lake.

In the unit of laminated silt and clay, the silt beds are of a magnitude thicker than the clay beds. This indicates a high amount of suspended material during the sedimentation of the unit.

The dip of the laminae in the silt and clay unit indicates that the unit was displaced after sedimentation. The lack of shear structures suggests that the unit was consolidated before the displacement occurred.

The displacement was either caused by subsidence when buried ice was melted alternatively due to glaciotectionic pressure.

The top of the unit of laminated silt and clay was eroded by a fluvial stream. The bedding planes were cut by the erosion indicating that the erosion took place after the displacement of the unit.

The erosion traces on the surface of the silt and clay unit indicate that the eroding stream was flowing towards a southern sector (Fig. 132), which is against the topography. Water flowing against the contour lines must have run in a subglacier tunnel.

The surface of the unit of silt and clay is about 10 m lower in the western part of the pit, than in the eastern parts, indicating a more intensive erosion in the western part of the area. It is possible that the glaciofluvial stream had its main channel in the western parts of the pit, or eventually further westwards.

The unit of silt and clay is superimposed by sand and gravel deposited in/or very close to the mouth of a glaciofluvial conduit. The fluvial sediments show a fining upwards sequence and in the upper parts of the sequence, there are units of silt and clay deposited in low energy water. In the lower units of the fluvial sediments, there are many intraclasts of laminated silt and sand. Some of the intraclasts consist solely of medium and fine sand. The intraclasts were deposited together with pebbly sandy gravel. The intraclasts must have been frozen or consolidated by chemical precipitation, which there are no traces of, when the intraclasts were eroded.

Trough-bedded, cross-laminated sand and gravel are the most common sedimentary units in the sections. This type of sedimentary structure is typically formed by migrating dunes in shallow flowing water (braided streams). This type of sediment is also found in sediment deposited in a glaciofluvial conduit or where a jetstream enters a low energy

water.

In the upper part of the sections there are many sequences of through-bedded cross-laminated sand, superimposed by type A ripple sand, superimposed by type B ripple sand and silt, superimposed by sinusoidal ripple sand and silt, which is grading into draped laminated silt and clay. This type of sequence might be the result of turbidity currents (Bouma 1962 and others). The sequences are similar to the density undercurrents, described by Gustavson (1975), from a glacial lake in front of a recent glacier in Alaska.

According to Miall (1976) the dip of the laminae, in trough-bedded cross-laminated sediments, gives a good accuracy of the paleocurrent of the depositing stream.

The paleocurrent analysis in the sections, gives a very confusing impression. In the lower parts of section 1, paleocurrents towards a southern sector dominate, while in the upper parts, the paleocurrent seems to have been towards the northern sector. In section 2 the paleocurrent is shifting throughout the whole section and in section 3 the water seems to have been flowing towards the north at all times.

The fining upwards in the sections, indicates a successively more distal position to the glaciofluvial conduit or a shift in the drainage pattern.

The bedding planes in the sections usually dip about 10° towards the northwest, but there are no extensive faulting in the sections, indicating melting of ice-support or a glaciotectionic deformation.

The bottom of the gravel beds in the pit is about +168 m. If a glacier occupied the southern parts of the Vättern basin, the thresholds were at about +220 m. One of the cols is less than 10 km south of Damnhagen. The unit of silt and clay in the lowest parts of section 1 and 2, was deposited in deep low energy water. The unit was displaced and then eroded by water flowing in a southerly direction. Since there is no extensive faulting in the overlying sorted sediments, the displacement must have occurred before the overlying sediments were deposited. The fact that the displacement occurred before the erosion makes it unlikely, that the gravels and sand were deposited in a subaerial position on top of stagnant ice, which then successively melted. This close to the threshold, the silt and clay needed low energy water to be deposited, which indicates that the unit is well below the level of the threshold. Consequently the erosion of the silt and clay unit must have occurred in a subglacier conduit.

Whether the sands and gravels were deposited in a subglacier or subaquatic environment is not clear. The width of the deposit favors deposition in a proglacial subaquatic position.

The paleocurrent within a glaciofluvial conduit, is likely to be towards the glacier front. The shifting paleocurrents in the sections suggest that the sand and gravels were deposited in a proglacial subaquatic position. It is possible that parts of the sediment were deposited by turbidites.

Consequently, the erosion of the silt and clay unit occurred subglacially and the sand and gravel were deposited in a proglacial subaquatic position. The major drainage channel was situated in the western part of the

gravel pit or perhaps further towards the west. The drainage was towards a southern sector. Dunes migrating towards the north are usually found in section 2 and 3. They were either formed by compensation streams to the major drainage stream or by turbidity currents.

The diamicton units, in the uppermost parts of the sections, were probably deposited by sediment gravity flows.

The stratigraphy at Dammhagen is not directly correlative with the stratigraphy in the lower part of the Vättern basin. The rock fragment composition of the lowest diamicton unit, is not comparable with any of the diamicton units in the lower Vättern basin, but it might be related to the lowest diamicton units in the Tenhult valley.

There are two possible ways to correlate the stratigraphy at Dammhagen with the stratigraphy in the lower Vättern basin. The laminated silt and clay in the bottom of the gravel pit at Dammhagen, is correlatable either with the Kaptensbo beds or with the Sanna beds.

In the first alternative the underlying diamicton unit predates the Kaptensbo beds and perhaps this diamicton represents the "main" glaciation. In this case, the overlying gravels and sands correspond with the Rosenlund diamicton. The Sanna beds are perhaps correlative with the upper parts of the sediments at Dammhagen, which were deposited in low energy water. The Öxnehaga diamicton is either not represented in the site or corresponds with one of the upper units of gravel. The Ekhagen clay is not found in the sections or might perhaps be correlated with the fine grained sediments in the uppermost parts of the sections. The ravines in the vicinity of Dammhagen were formed when the Ryhov sand was deposited (the rock fragment composition is almost the same).

In the second alternative the lower unit of silt and clay is correlated with the Sanna beds. In this case the underlying diamicton would be correlated with the Rosenlund diamicton and the overlying unit of glaciofluvial sediments, correlated with the Öxnehaga diamicton. The fine grained sedi-

ments in the upper parts of the sections are here correlated with the Ekhagen clay.

Southeast of Lake Lovsjön (Fig. 2), about 5 km southeast of Dammhagen, there are boulders lying on top of laminated sand. The area is close to one of the thresholds to the south of the Vättern basin, and the area is at about the same level (+220 m) as the thresholds. The boulders were deposited by stranded ice-bergs. The boulders might correspond to the Öxnehaga diamicton in the area.

The grain-size and the rock fragment composition of the lower diamicton at Dammhagen, and the Rosenlund diamicton, are very different, which favors the first alternative of stratigraphic correlation. The Ekhagen clay and the Öxnehaga diamicton cover only minor areas in the Taberg valley, which could explain why these stratigraphic units are not represented. Furthermore, it is not likely that fine grained clay would have been deposited this close to the threshold, where a major part of the glacial lake in the Vättern basin was drained.

9:5:5 Conclusions

The lowest unit of diamicton is most likely a till composed of local material. The till was deposited earlier than the Kaptensbo beds in the Vättern basin. The overlying units, of first laminated sand, and then laminated silt and clay, were deposited in a glacial lake. After consolidation the silt and clay unit was displaced. After the displacement, the top of the unit was eroded by water flowing towards a southern sector. The erosion probably took place in a subglacial tunnel. The units of laminated sand and laminated silt and clay are correlated with the Kaptensbo beds.

The overlying unit of glaciofluvial sediments were probably deposited in a proglacial sub-aquatic environment. The glaciofluvial stream flowed southwards. The fining upwards sequence indicates a successively more distal position to the glaciofluvial tunnel. The units of sands and gravels correspond to the Rosenlund diamicton.

10 The Landsjödalen valley

The Landsjödalen valley is a tributary valley trending northeast-southwest to the Vättern basin (Fig. 2). A large part of the valley is occupied by lake Landsjön (Fig. 137). The waterlevel in the lake is today at about +145,5m, but the lake has been artificially lowered, at least 3,5 m (Munthe and Sandegren in Geijer 1951).

Most of the valley is covered by fine-grained water-sorted sediments, rhythmically laminated clay and silt is dominating. In the northeast end of the valley, clay is most common and the sediment in the surface is coarsening towards the southwest (Svantesson 1985) where units of sand are common.

There are two different stratigraphic units of sand in the valley. The stratigraphically lowest sand units are found on the valley slopes, where they reach at the most about +225 m. These deposits are usually glaciofluvial deltas, with ice-contact slopes facing towards the bottom of the valley.

The stratigraphically upper unit of sand is found below +160 m and is of postglacial origin.

In the south-east facing slopes northwest of lake Landsjön the bedrock is exposed in many places (Svantesson 1985). The tributary valleys in the slope are filled with sandy silty diamict. This diamict is very easily eroded, which is evident from the many trenches in the slope (Fig. 137).

At the northern side of lake Landsjön, a special investigation is made of the glacial striae in the slope (Fig. 138).

10:1 Kaxholmen

The site is situated about 1 km east of Kaxholmen (Fig. 137). The section starts at about +225 m and is described from bottom to top (Fig. 139).

10:1:1 Description

2,5 m massive yellow brown sandy diamict (Dm). Clasts are rounded-subangular in the unit. In the lower part of the unit, the diamict is homogeneous and in the upper part, it is heterogeneous. The rock fragment composition is 56,59,62 and 66% Visingsö Group of Rocks and 44,41,34 and 34% crystalline rocks. In the samples with 62% Visingsö Group Rocks there is 5% Paleozoic limestone. In the upper part of the unit there are lenses of sorted sediments and a lens of a diamict with properties dissimilar to those in the unit. The lenses are found west of a big boulder. The stratigraphy in the lens is as follows:

0,3 m massive yellow brown pebbly gravel (Gm). The unit becomes thicker towards the western part of the section. The sediment is poorly sorted. The rock fragment composition is 55% Visingsö Group of Rocks and 45% crystalline rocks.

0,5 m horizontally laminated redbrown gravelly sand (Sh). The unit is tapering towards the west. The rock fragment composition is 67% Visingsö Group of Rocks and 33% crystalline rocks.

0,05 m horizontally laminated fine sand and coarse silt (Sh).

0,2 m laminated redbrown clay, silt and diamict (Fl,Dm). There are 13-20 clay laminae in the unit. The thickness of the laminae varies between 1-5 mm. The thickness of the interbedded laminae of diamict increases towards the west. In the contact to the boulder the laminae are deformed and bent upwards. The upper contact is conformable.

0,5 m massive brown sandy silty diamict (Dm). The rock fragment composition is 90 resp. 81% Visingsö Group of Rocks and 10 resp. 19% crystalline rocks.

On top of the lens there is about 0,3 m of

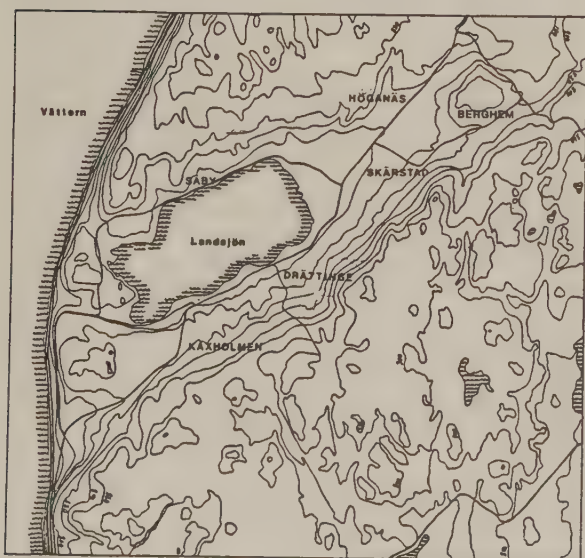


Fig. 137. Topographic map of the Landsjödalen valley, with 10 m equidistance.

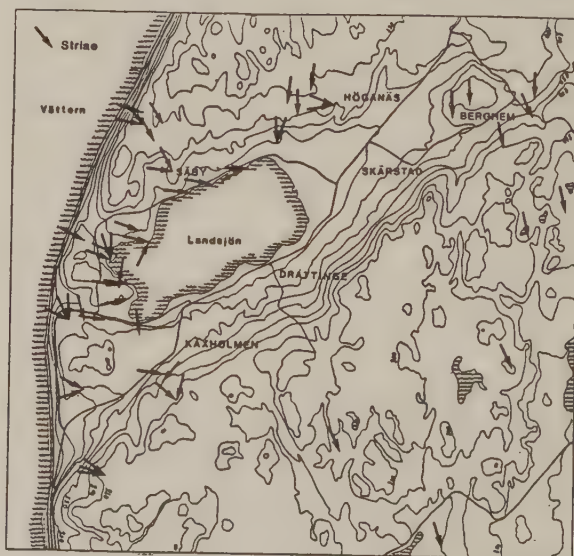


Fig. 138. Striae in the Landsjödalen valley.

the same kind of diamicton as below the lens. **0,5 m massive silty clay diamicton (Dm)**. The diamicton is reddish brown and spotted with light gray. The unit is coarsening upwards. The rock fragment composition is 87 resp. 94 % Visingsö Group of Rocks and 13 resp. 6% crystalline rocks.

0,7 m massive grayish brown sandy silty diamicton (Dm). The unit is fining upwards. The unit is heterogeneous and unconsolidated. The rock fragment composition is 81% Visingsö Group of Rocks and 19% crystalline rocks.

1,5 m stratified grayish black diamicton with organic content (Ds,C).

10:1:2 Discussion

In the lens in the upper part of the lower diamicton unit there is a diamicton bed with a different grain size and rock fragment composition than the surrounding diamicton. There are also water sorted sediments. The



Fig. 139. Log from Kaxholmen.

sand and gravel units in the lens have a rock fragment composition similar to the underlying diamicton unit. The clay laminae in the lens indicate deposition in a subaquatic environment. The fining upward sequence in the lens from gravel to laminated clay indicates a successively more distal position to the sediment supply, a cessation of the sediment transport, or an elevation of the waterlevel. The introduction of a diamicton with a different, more local rock fragment composition, can be explained in three different ways: 1) The diamicton is a till from a "new" glacier that entered the valley. 2) The material in the diamicton was derived from a different part of the glacier than the underlying diamicton. 3) The diamicton was dropped from ice-bergs.

The first alternative is not likely, because the diamicton unit is found in a lens, and diamicton of the same kind is found in the underlying unit of rhythmically laminated silt and clay.

The second alternative is possible, if the lower diamicton unit is solely built up of debris flow deposits from a melting glacier tongue in the valley. In this case, it is the furthest transported material, thus situated higher up in the glacier, that was first deposited, and then the more locally derived material was deposited on top of this.

The third alternative is possible but in this case the waterlevel in the Landsjödalen valley must have been higher than +230m, which is at least 10 m higher than the thresholds to the south.

The deformation structures in the sand and clay units indicate that the sediments in the

lens were lowered opposite the big boulder in the section. This suggests, that the bed of yellow brown diamicton overlying the lens, is composed of one or several debris flow deposits.

The superimposed unit of diamicton has a grain-size and rock fragment composition similar to the uppermost diamicton unit in the previously described lens. This suggests that redeposition of sediments, deposited in a glacial lake is also possible. The lack of stratification favors the second alternative. The overlying unit of grayish brown sandy diamicton has a rock fragment composition similar to the underlying unit, suggesting that the material is derived from the same source.

It is likely that the water sorted sediments and the diamicton unit in the lens were deposited on top of a stagnant ice body superimposing or enclosing the underlying diamicton. When the stagnant ice melted the sediments were deformed and parts of the lower diamicton were liquefied and flowed over the already deposited sediments. The overlying clayey diamicton was deposited by drop from ice-bergs. If this is true, the lower part of the lowest unit is a till.

The uppermost unit in the section was deposited by sediment gravity flow processes. The organic content indicates that the sediment was postglacially redeposited.

10:1:3 Conclusions

The rock fragment composition in the lower and upper diamicton units indicates different origins. The unit of laminated silt and clay indicates an episode of deposition in low energy water.

The deformation structures in the section suggest deposition in contact with stagnant ice.

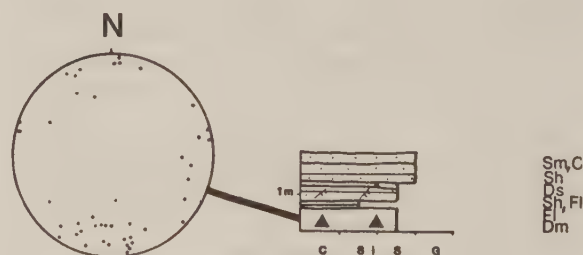


Fig. 140. Log from Saby.

10:2 Saby

About 500 m north of Saby, on the northern side of lake Landsjön (Fig. 137), there is a small sand pit. The bottom of the section is at about +200 m. The stratigraphy in the pit is described from bottom to top (Fig. 140).

10:2:1 Description

0,6 m massive gray sandy silty diamicton (Dm). The clay content in the unit is about 12%. One fabric analysis was made in the

lower part of the unit. The orientation of clasts long axes is shown in Fig. 140. The rock fragment composition is 64% Visingsö Group of Rocks and 36% crystalline rocks. The contact to overlying unit is interbedded.

0,2 m rhythmically laminated silt and clay (Fl). In the unit, 10 laminae of fine clay can be counted. The lamination is slightly disturbed.

0,1 m horizontally laminated sand, with thin beds of silt and clay (Sh, Fl). The lamination is faint. Gravel sized intraclasts of clay are found in the unit. The lamination is slightly disturbed.

0,2 horizontally laminated sand and coarse silt (Sh).

0,1 m small-scale cross-laminated sand with thin beds of silt (Sr, Fl). The unit consists of type-A ripple sand and draped laminated silt. The upper contact is erosive.

0,1 m stratified light gray silty sandy diamicton (Ds). Short deformed units of clay are found in the unit. The unit is fining upwards and bigger clasts are clustered in the lower part of the unit. The rock fragment composition is 73% Visingsö Group of Rocks and 27% crystalline.

0,5 m horizontally laminated sand (Sh).

0,3 m massive sand with organic material (Sm, C (soil)).

10:2:2 Discussion

The fabric analysis in the lower diamicton unit shows a clustering of clasts long axes around 190° , with a dip of about 15° . This is the approximate direction of the slope, and also the direction of one of two striae assemblages of the area (see below). The dip of clasts long axes have a dip in the opposite direction to the striae. This indicates that the diamicton was deposited either under a glacier moving towards the south or that the unit is composed of debris flows coming down the valley slope. Debris flows moving northwards from a glacier tongue in the Landsjö dalen valley is also possible.

Debris flows running down the slope were not likely to stop in the middle of the slope but would continue to the bottom of the valley, except if a glacier tongue hindered the flow. In both described suggestions of the diamicton being a sediment gravity flow deposit, a glacier tongue must have been very close to the site.

The diamicton is grading into a unit of rhythmically laminated silt and clay deposited in low energy water. A small pond existed either between the valley side and the glacier, or the sediment was deposited in a glacial lake. The grading lower contact suggests ice contact, the short period of sedimentation and the overlying sediments deposited by running water, favor the first alternative.

Superimposing the unit of silt and clay there is a unit of faintly laminated sand with intraclasts of clay. A faint lamination could have been formed by the "freezing" (Middleton 1967) of a sediment gravity flow. Intraclasts of silt and clay are common in sediment gravity flows.

The overlying units of silt and clay indicate deposition in shallow, sometimes flowing water.

The upper diamicton unit is stratified, containing deformed beds of clay. During the

deposition of the unit the underlying sediments were probably eroded but not deformed. All properties indicate that the unit was deposited by debris flows.

The uppermost laminated sand indicates a new phase of deposition in shallow water.

10:2:3 Conclusions

The unit of rhythmically laminated silt and clay was deposited in a pond, between the valley side and the glacier, in the Landsjö dalen valley. The period of low energy water had a short duration. The sedimentation in calm water was replaced by sedimentation in flowing water, and deposition from sediment gravity flows.

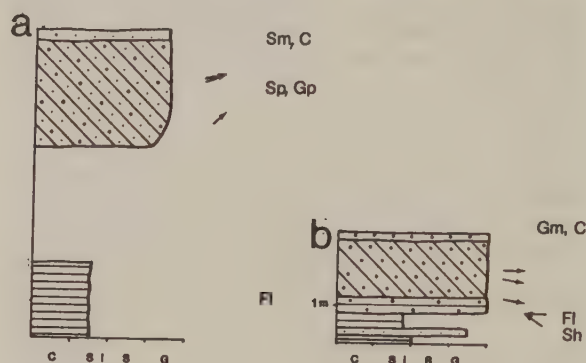


Fig. 141. Log from a) Höganäs and b) Drättinge.

10:3 Höganäs

About 350 m north west of the farm, Höganäs (Fig. 137) there is a gravel pit and a small cut in fine-grained sediments. The described stratigraphy is a compilation of the two sections, which are possible to correlated in the field. The section with fine-grained sediments starts at about +200 m (Fig. 141).

10:3:1 Description

2,0 m rhythmically laminated silt and clay (Fl). There are thin beds of sand in the unit. The lamination is disturbed.

3;0 m scree.

2,8 m of one set of planar-bedded cross-laminated sand and gravel (Sp, Gp). The grain-size composition has a tail of fines. Clasts are often covered with a "skin" of silt and clay. Intraclasts of rhythmically laminated silt and clay are commonly found in the unit. The rock fragment composition is 70% Visingsö Group of Rocks and 30% crystalline. About 1 m up into the unit the laminae are dipping 19° towards 48° , 2 m up, 19° towards 74° and on the same level, but at another spot 15° towards 77° .

10:3:2 Discussion

The gravel deposit hangs on the steep slope, and has an ice-contact towards the bottom of

the valley.

In the bottom of the pit the gravel is superimposing laminated clay, suggesting that the sediment covered by scree is laminated clay. If this is true there is a high column of rhythmically laminated silt and clay here, at least 5 m high. Such a high column, if not repeated, represents a long period of deposition in a glacial lake.

The planar-bedded sand and gravel were deposited by avalanches down the foreset slope. The material was brought by water, flowing in an east-north-easterly direction, which was parallel to the contourlines. The grain size composition with a fine tail indicates that there is a lot of fine sediments in suspension in the water. Here arguments suggest deposition by a glaciofluvial stream. The topographic position of the deposit indicates that the glaciofluvial stream is lateral to a glacier tongue in the Landsjödal valley.

The intraclasts of laminated silt and clay indicate that the flowing water eroded previously deposited consolidated sediments.

The erosion of already deposited sediments by a lateral glaciofluvial stream, suggests a glacier advance over already deposited sediments.

10:3:3 Conclusions

The sand and gravel deposit is the foreset bed in a delta. The unit was deposited by a lateral glaciofluvial stream, flowing towards the east-north-east. The lower part of the section is the bottomset bed of the delta, or a previously deposited glacial lake sediment. The stratigraphy in the section indicates a glacier readvance in the Landsjö dalen valley.

10:4 Drättinge

About 1 km east north east of Drättinge there is a small gravel pit (Fig. 137). The top of the gravel deposit reaches about +225 m and the lowest part of the deposit lies at about +200 m. The bottom of the pit is at about +215 m. The gravel deposit is superimposing rhythmically laminated silt and clay. In the western part of the deposit, laminated silt and clay superimpose the gravel. The section is described from bottom to top (Fig. 141).

10:4:1 Description

0,2 m laminated silt (Fl).

0,15 m horizontally laminated gravely sand (Sh).

0,4 m laminated silt with thin beds of clay (Fl).

0,4 m trough-bedded cross-laminated sandy gravel (Gt). The grain-size composition has a tail of fines. The rock fragment composition is 82% Visingsö Group of Rocks and 18% crystalline. In the lower part of the unit the laminae in the troughs dip 23° towards 305° resp. 11° towards 270°. In the upper part of the unit the laminae in a trough dip 5° towards 98°.

1,5 m one set of planar-bedded cross-laminated gravel (Gp). Many intraclasts of laminated clay are found in the unit. About 0,5 m up in the unit the laminae dip 17°

towards 98° and at two places 0,8 m up in the unit 34° towards 91°.

0,2 massive gravely soil (Gm,C).

10:4:2 Discussion

Rhythmically laminated silt and clay is found stratigraphically below the sediments in the section. These fine-grained sediments were deposited in a local glacial lake or a bigger ice-dammed lake, covering the Landsjö dalen valley.

The position of the site, hanging on the valley side, indicates lateral glaciofluvial deposition with ice-contact or deposition by a stream, that came down the valley slope to a low energy water with a waterlevel of about +225 m.

The paleocurrent direction in the lower part of the trough-bedded cross-laminated sandy gravel, suggests the latter way of deposition. The unit was perhaps deposited by an under-current coming down the valley side. A meandering lateral glaciofluvial stream could also have produced sediments with the described properties.

The planar-bedded cross-laminated gravel displays a paleocurrent towards the east and was probably deposited by a lateral glaciofluvial stream flowing eastwards in the valley.

The high amount of intraclasts of laminated silt and clay indicates erosion of the substratum by the glacier, since the stream was lateral to a glacier tongue, when the stream entered the ice-dammed lake. The intraclasts suggest that the fine grained sediments were consolidated before they were eroded.

It is likely that the described section is a glaciofluvial delta. The lack of a topset bed suggests that the aggradation of sediments did not reach the surface of the glacial lake.

When the glacier tongue in the Landsjödal valley retreated, the area around the site was covered by laminated silt and clay. It is likely that the top of the gravel deposit was too close to the surface of the glacial lake to be covered by fine-grained sediments.

10:4:3 Conclusions

The coarse-grained sediments in the upper part of the section are deposited with ice-contact. They were deposited by a lateral glaciofluvial stream flowing eastwards into an ice-dammed lake with a waterlevel of at least +225 m. Before the coarse grained sediments were deposited, a glacier tongue advanced eastwards over fine-grained sediments in the valley, at least as far as to the position of this site.

10:5 Glaciofluvial deposits in the Landsjödal valley

The situation of glaciofluvial deposit in the Landsjö dalen valley are shown in Fig. 142.

10:5:1 Description

The Landsjödal valley is mapped by the author for the geological map of Jönköping SV (Svantesson 1985).

Deposits of glaciofluvial sediments have only been found in the valley slopes and not in

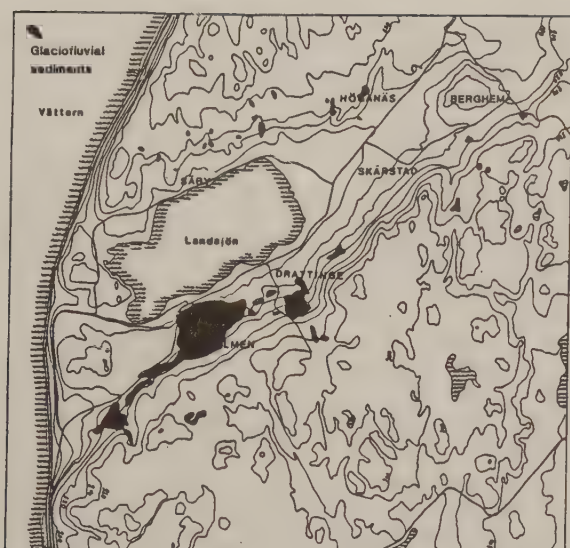


Fig. 142. Map of glaciofluvial deposits in the Landsjödalen valley.

the lower central parts of the valley. Some of the deposits display ice-contact morphology and others show erosional morphology. The paleocurrent directions in the sediments are shown in Fig. 143. Two main paleocurrent directions can be distinguished in the sediments. One of the directions is away from the valley slopes and the other is along the valley towards the east. In the glaciofluvial deposits, horizontally laminated- and planar-bedded cross-laminated sand and gravel are dominating.

10:5:2 Discussion

The glaciofluvial deposits at Höganäs, Drättinge and in the Kaxholmen area, are ice-contact deltas without the topset bed (Fig. 142). The genesis of the other glaciofluvial deposits in the area is not known, but their topographical position, ice-contact morphology, internal structures and the paleocurrent directions suggest deposition either from a lateral glaciofluvial stream or from a stream coming down the valley slope into a low energy water.

10:5:3 Conclusions

A glacier tongue occupied the Landsjödalen valley as the glaciofluvial sediments were deposited. The sedimenttransporting water ran either down the valley slopes or flowed lateral to the glacier tongue. All investigated glaciofluvial deposits in the Landsjödalen valley show evidence of deposition in low energy water. The water-level during the deglaciation exceeded +225 m.

10:6 Investigation of striae in the Landsjödalen valley

A special investigation of the striae and glacial sculpture in the bedrock was made on

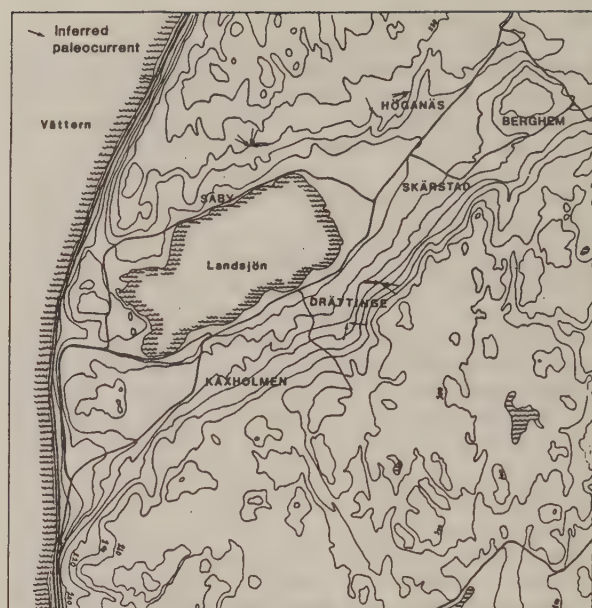


Fig. 143. Paleocurrents in the glaciofluvial deposits in the Landsjödalen valley.

the northern side of Lake Landsjön.

10:6:1 Description

The directions of the striae in the valley are shown in Fig 138. Two groups of striae directions are found in the valley. In the first group the striae, point between $30-140^\circ$ and in the second, between $145-190^\circ$. The first group of striae are not found above +230 m and not east of Skärstad (Fig. 138). These striae tend to have a more easterly or northeasterly (Fig. 138) trend in the lower and western part of the valley than in the higher and eastern parts of the valley. On the north side of the lake the striae in this group usually have a northeasterly trend. On the south side of the lake the striae in this group point towards the east or the east southeast. In the lower parts of the valley the whale-back rocks have the stoss-side towards a western sector. The second group of striae trends towards a southern sector and does not seem to be dependent of the topography. Striae in this group are found in any topographical position in the area, but are more sparse in lower parts of the valley.

10:6:2 Discussion

It has not been possible to distinguish the relative age between the two groups of striae, but the fact that the south trending striae are sparse at low levels, and that the east trending striae are not found above +230 m suggests that the east trending is the system younger than the south trending one. According to Svantesson (1985), a site not investigated here, the east trending striae are the youngest ones.

Striae pointing towards the east are not found east of Skärstad. At Berghem, a bedrock

hill in the central parts of the valley about 1 km northeast of Skärstad, only striae pointing towards the south are found. This might indicate, that the eroding glacier moving eastwards, did not reach this far into the valley. The small extension of the area with east trending striae also favors the interpretation that the east trending striae are the youngest ones in the area. It also means that the glacier cutting these striae did not reach east of Skärstad or were not powerful enough to erode striae east of Skärstad.

It is likely that a glacier tongue entered the valley in the western end after a first deglaciation. The glacier appears to have had a rather low gradient.

10:6:3 Conclusions

The striae pointing towards a southern sector are older than the striae pointing towards an eastern sector.

The striae indicate that, after a first deglaciation a glacier tongue moved eastwards in the Landsjö dalen valley. The glacier readvance did not reach east of Skärstad and did not cut striae at higher levels than +230 m.

10:7 The deglaciation of the Landsjö dalen valley

10:7:1 Discussion

The striae in the valley indicate a glacier advance into the valley, after the main glacier melted.

In the valley glaciofluvial deposits, with ice-contact morphology and a paleocurrent

towards an eastern sector, are hanging on the valley slopes. At least at two places, glaciofluvial sediments are superimposing thick units of rhythmically laminated silt and clay. In the glaciofluvial deposits, intraclasts of laminated silt and clay are common. This argument indicates that a glacier advanced into a glacial lake, over consolidated fine-grained sediments. The glaciofluvial sediments were deposited during the melting of the glacier tongue, by lateral streams flowing eastwards into an ice-dammed lake.

If this is so, it is likely that diamicton units with different rock fragment composition were derived from two different glaciers, with a deglaciation in between.

All arguments listed above indicate a glacier entering the valley in the southwestern end. The glacier tongue moved in a northeasterly direction. This indicates that the glacier must have had a gradient roughly in the direction of the valley, that is towards northeast. Such a gradient could have been produced, if there was a local dome in the Vättern basin. It is likely the dome was south or west of the Landsjö dalen valley.

10:7:2 Conclusions

During the deglaciation, an ice-dammed lake was formed in the Landsjö dalen valley. In the glacial lake rhythmically laminated silt and clay were deposited.

A glacier advanced from southwest over the rhythmically laminated sediments. The glacier tongue reached to about Skärstad (Fig. 158). During the subsequent deglaciation, deltas were deposited on the valley slopes by lateral glaciofluvial streams. Rhythmically laminated sediments were deposited in the glacial lake northeast of the glacier tongue.

11 Sites in the area south of the water-divide

11:1 Eckersholm

The site is situated about 10 km south of Barnarp (Fig. 144) in an area with mounds and ridges of glaciofluvial sediments. The section is cut into a mound of glaciofluvial sediments. The section starts at +210 m (Fig. 145).

11:1:1 Description

0,4 m one set of planar-bedded cross-laminated sand (Sp). Intraformational normal faults are found in the unit. The laminae dip 10° towards 119° .

0,6 m massive sandy and pebbly gravel (Gm). The rock fragment composition is 43% Visingsö group of Rocks 55% crystalline and 2% of Paleozoic limestone.

0,5 m planar-bedded cross-laminated sand (Sp). In the lower part of the unit the laminae in one set dip 12° towards 110° and in another set, in the upper part, 21° towards 84° . The upper contact is erosive.

0,25 m massive sandy and pebbly gravel (Gm). The lower contact is erosive.

0,6 m planar-bedded cross-laminated sand (Sp). There are intraformational normal faults in the unit. In the lower part of the unit the laminae in a set dip 7° towards 95° and in the upper part, 15° towards 79° .

0,6 m horizontally laminated sandy and pebbly gravel (Gh).

0,3 m trough-bedded cross-laminated gravelly sand (St). The laminae in two troughs dip 25° towards 97° resp. 27° towards 158° .

0,2 m planar-bedded cross-laminated sand (Sp). The laminae in one set dip 8° towards 44° .

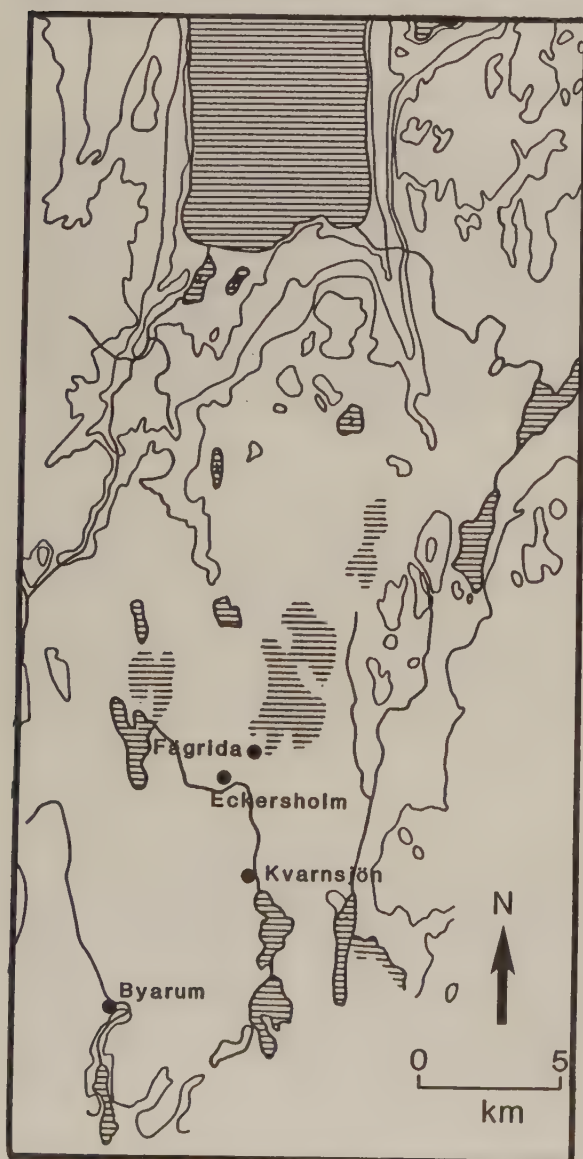


Fig. 144. The sites south of the water divide.

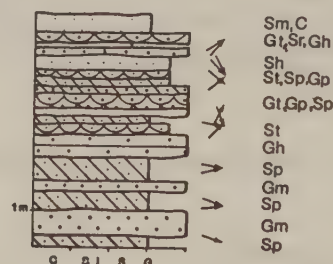


Fig. 145. The log 1 and 2 from Eckersholm.

0,2 m planar-bedded cross-laminated sandy gravel (Gp).

0,4 m trough-bedded cross-laminated sandy gravel (Gt). The laminae in a trough dip 35° towards 29° .

0,2 m planar-bedded cross-laminated sandy gravel (Gp).

0,2 m planar-bedded cross-laminated gravelly sand (Sp). The unit is fining upwards. The laminae in one set dip 32° towards 126° .

0,2 m trough-bedded cross-laminated gravelly sand (St). The unit is fining upwards. The laminae in three troughs dip 22° towards 50° , 8° towards 152° resp. 31° towards 137° .

0,4 m horizontally laminated gravelly sand (Sh).

0,2 m horizontally laminated pebbly gravel (Gh). The rock fragment composition is 44% Visingsö group of Rocks and 56% crystalline.

0,05 m small-scale cross-laminated fine sand (Sr).

0,3 m trough-bedded sandy gravel (Gt). The unit is fining upwards. The laminae in two troughs dip 17° towards 39° resp. 24° towards 55° .

0,5 m massive sandy soil (Sm,C).

11:1:2 Discussion

Both the morphology of the glaciofluvial sediments and the intraformational tectonic structures indicate that the sediments were deposited with ice-contact. The sedimentary structures indicate deposi-

tion in high energy water moving towards an eastern sector. The topographic position and the sedimentary structures suggest subaerial deposition in a braided stream. It is likely that the sediments were deposited on stagnant ice.

11:2 Fägrida

Two sections are investigated at Fägrida about 800 m northeast of Eckersholm (Fig. 144). The sections are about 250 m apart.

11:2:1 Section 1

Section 1 is situated at an old peat factory close to the peat bog Konungsömmossen. The section is described from bottom to top and starts at about +215 m (Fig. 146).

2,8 m one set of planar-bedded cross-laminated gravelly sand (Sp). About 1 m up in the unit, the laminae dip 18° towards 94° , 1,5 m up, 16° towards 73° and 2 m up in the unit 5° towards 25° . At another spot about 15 m to the west the laminae dip 15° towards 69° about 1,5 m up in the unit.

0,2 m massive sand with organic material (Sm,C).

11:2:2 Section 2

Section 2 is situated close to the farm house and is an excavation for a garage. The section starts at about +215 m (Fig. 146).

3,0 m one set of planar-bedded cross-laminated sand (Sp). Thin beds of silt and gravel are found in the unit. The unit is coarsening upwards. There are many intraformational normal faults in the unit. The dip of the laminae are measured in 10 places. The direction varies between $64-162^\circ$ with a mean of 107° and a mean dip of 18° .

0,5 m planar-bedded cross-laminated sandy gravel (Gp). Four measurements of the dip of the laminae were made in the unit, with a mean of 24° towards 120° .

0,5 m massive sandy soil (Sm,C).

11:2:3 Discussion

The sections are situated in an area with short ridges and mounds of sandy sediments. Both the morphology and the intraformational normal faults indicate deposition with ice-support.

The sedimentary structures suggest deposition of flowing water into a low energy water. The water was flowing in a south-easterly direction. The areas east and northeast of the sections are depressions filled with peat, with no clay under the peat (Lundqvist 1942). It is likely that these depressions were filled with stagnant ice and that there existed a lateral glacial lake in which deltas were deposited.

11:2:4 Conclusions

The sediments around Fägrida were deposited on stagnant ice or with ice-support. The sediment were transported by a meltwater stream running towards the south-east or the east.

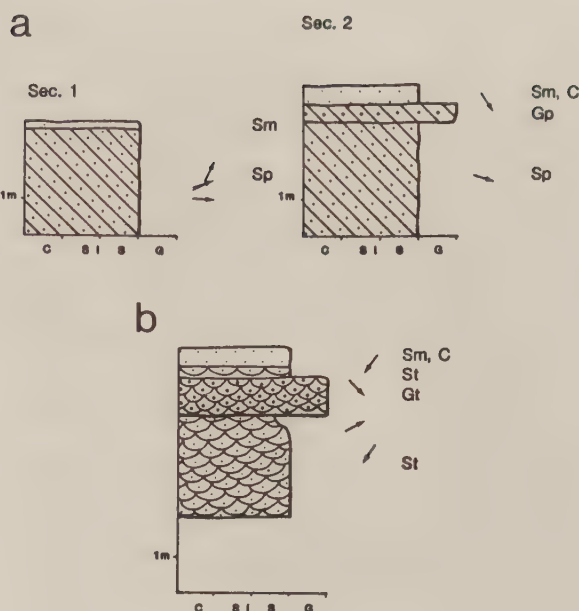


Fig. 146. Log from a) Fägrida and b) Kvarnsjön.

11:3 Kvarnsjön

The site is situated south of Kvarnsjön about 3 km south of Eckersholm (Fig. 144). The section starts at about +205 m (Fig. 146).

11:3:1 Description

2,0 m scree

2,5 m trough-bedded cross-laminated gravelly sand (St). Thin beds of gravel occur in the unit. The dip of the laminae were measured in 9 different troughs (Fig. 146). The mean dip is 13° towards 212° .

0,2 m trough-bedded cross-laminated sand (St). In one trough the laminae dip 8° towards 65° .

1,0 m trough-bedded cross-laminated sandy pebbly gravel (Gt). The unit is fining upwards. In one trough the laminae dip 14° towards 136° . The lower contact is erosional.

0,3 m trough-bedded cross-laminated gravelly sand (St). The laminae in a trough dip 16° towards 216° .

0,5 m massive sand with organic material (Sm,C (soil)).

11:3:2 Discussion

The sediments in the site were deposited by flowing water. The water was running towards a southern sector.

11:4 Byarum

The site is situated about 250 m south west of lake Byarumssjön (Fig. 144). The site is a sand pit with a bottom at about +200 m. The sand pit is cut in a flat sand plain with some hollows interpreted as kettle-holes. Two sections are described from the site: one in the western wall (Fig. 147) and the other in the eastern wall (Fig. 147).

[illegible]

11:4:1 Section 1

2,3 m trough-bedded cross-laminated sand (St). Beds of gravel occur in the unit.

0,6 m massive sand with organic material (Sm,C (soil)).

0,7 planar-bedded cross-laminated gravely sand (Sp). Bigger clasts are enriched in the lower contacts of the beds. About 0,2 m up in



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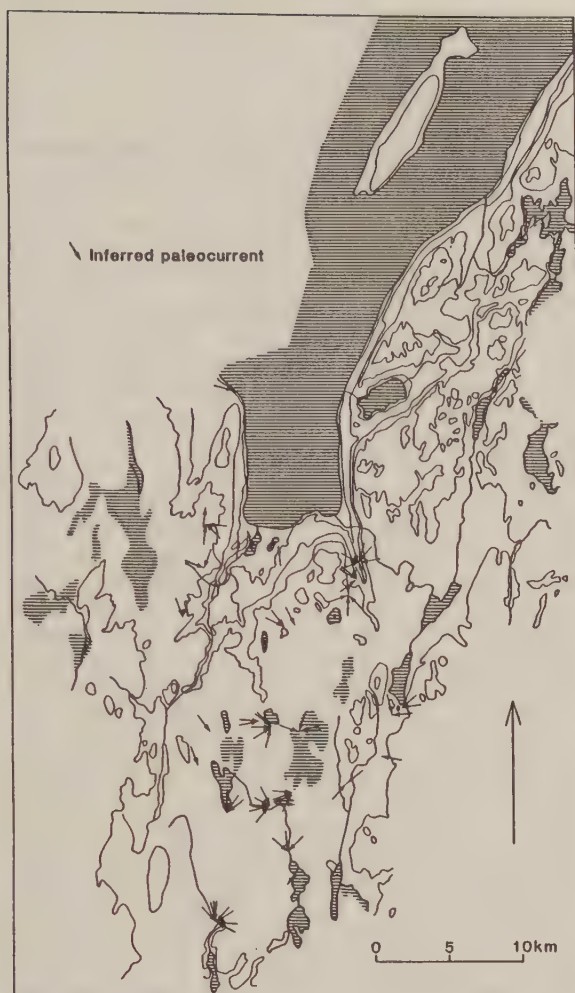


Fig. 149. The direction of dip of the foreset laminae in planar- and trough-bedded cross-laminated sand and gravel from different sites in the investigation area.

the unit, the laminae dip 21° towards 236° and about 0,5 m up 10° towards 290° .

0,3 m planar-bedded cross-laminated sand (Sp). The laminae dip 6° towards 55° .

1,0 m trough-bedded cross-laminated gravely sand (St). The laminae in one trough dip 21° towards 165° .

0,1 m small-scale cross-laminated fine sand (Sr). The unit is dipping 8° towards 357° .

0,9 m planar-bedded cross-laminated fine sand

(Sp). The laminae in a set dip 18° towards 138° .

0,2 m horizontally laminated gravely sand (Sh). The unit is dipping 4° towards 359° .

0,4 m trough-bedded cross-laminated sand (St). The laminae in a trough dip 12° towards 274° .

0,3 m planar-bedded cross-laminated sand (Sp). Thin beds of gravel occur in the unit. The laminae in a set dip 10° towards 229° .

0,6 m trough-bedded cross-laminated sand (St). The laminae in a trough dip 12° towards 295° .

0,5 m massive sand (Sm,C (soil)).

11:4:3 Discussion

The section is situated in an area with very gentle topography. The area is dominated by flat sand fields with hollows. The bedrock sometimes project through the sediments. The hollows are usually kettle-holes. The sand fields start in the area of the waterdivide in the north and can be traced to Värnamo in the south (about 60 km south of the waterdivide). At Byarum the sand field is about 5 km wide. Small sections in the area show the same type of structures as in the described sections (the paleocurrents in the sections are shown in Fig. 149).

The frequent normal faults in section 2 indicate that the hollow east of section 2 is a kettle-hole.

The paleocurrent analysis in the sections indicate that the sediments were transported by water running towards a southern sector.

The structures in the sections indicate sediment deposition in rather shallow water.

The large extension of the sand field and the internal structures suggest that the sand field is a sandur. The sediments are relatively fine-grained for a sandur. This might be due to a distal position to the glacier or lack of coarse particles in the Vättern basin, which in turn is due to soft rock qualities in the Vättern basin and the protogin zone. The second alternative seems to be the most likely because coarse sediment is only found in a few places in the northern end of the sandur plain.

11:4:4 Conclusions

The section is cut in a sandur plain. The sediments are transported southwards by a braided stream. The kettle-holes in the area indicate that the glacier was rather close during the sedimentation.

12 The stratigraphy in the investigation area

The stratigraphy at low levels in the Vättern basin is well documented (see above) and the correlations between the localities are quite easy to make. It is much more difficult to establish a stratigraphy for the other sub-areas and to correlate the units in the different subareas.

The most complete sections outside the lower Vättern basin are Mjälaryd in the Tenhults dalen valley and Dammhagen in the Tabergsån valley. If the units at these two sites are possible to correlate with one another and to the established stratigraphy in the lower Vättern basin, many valuable conclusions could be made. First the correlation problems with the Dammhagen section and other sites in the Tabergsån valley are discussed, secondly Mjälaryd and the sites in the Tenhults dalen valley and thirdly the stratigraphy of the Landsjödalen valley.

In connection with the discussion of the stratigraphy at Dammhagen correlations to the sites south of the waterdivide are made.

In the following text, the glacier depositing the Rosenlund diamicton is called the Rosenlund glacier and the glacier depositing the Öxnehaga diamicton is called the Öxnehaga glacier.

12:1 The stratigraphy at Dammhagen and the slopes of the Tabergsån valley

The lowest unit at Dammhagen is a displaced unit of rhythmically laminated silt, with thin laminae of clay. The most plausible correlation to the stratigraphy in the lower Vättern basin of this unit is to the Kaptenso beds. If this correlation is correct the overlying units of laminated gravels and sand would correspond with the Rosenlund diamicton. It has not been possible to find out if the Sanna beds, the Öxnehaga diamicton or the Ekhagen clay are represented in the section. The fluvial erosion in the vicinity of Dammhagen is correlated to the Ryhov sand (Fig. 2).

If this interpretation is correct, the ridges, mounds and plateaux of glaciofluvial sediments, with ice-contact morphology, south of the waterdivide, would correspond to the Rosenlund diamicton. The kettle-holes in the sandur further to the south were formed by the melting of stagnant ice left during the same glacier advance. It has not been possible to find out if the glaciofluvial sediment embedding the ice-bodies which formed the kettle-holes emanated from the Rosenlund glacier or from a later glaciofluvial drainage from the Vättern basin.

Another possible correlation of the lowest unit of laminated silt and clay at Dammhagen is with the Sanna beds. In this case overlying units of laminated gravel and sand are correlated with the Öxnehaga diamicton. This leads to the conclusion that the glacier depositing the Öxnehaga diamicton must have reached south of Dammhagen. Probably the ice front reached as far as Eckersholm and Fägrida (see above). The Öxnehaga diamicton has not been found at Ryhov, is sparsely represented at Tokarp and 500 m south of Tokarp and is not found further south. Because of

this, the correspondence between the Öxnehaga diamicton and the gravel and sand at Dammhagen is less likely.

There are only a few sites in the western slope of the Tabergsån valley, and the stratigraphic correlations can only be made with wide assumptions.

The striae from an eastern sector in the valley side and especially at Dalvik, were probably eroded by the same glacier which eroded the striae from a western sector in the Landsjödalen valley. The striae from a western sector seem to be the youngest in the western side of lake Vättern. In the Landsjödalen striae from an eastern sector are the youngest ones and they were probably eroded by the glacier depositing the Öxnehaga diamicton. If the striae from the eastern sector were eroded by the same glacier, then the diamicton superimposing the bedrock knob at Dalvik could be correlated to the Öxnehaga diamicton. The upper diamicton unit has a similar grain size composition, rock fragment composition and stratigraphic position as the diamicton unit at Dalvik. At Vilhelmsro the deposition of the Öxnehaga diamicton is connected with the deformation from an eastern sector. A correlation of the upper unit at Dalvik to the Öxnehaga diamicton suggests that the upper diamicton unit at Samset also belongs to the Öxnehaga diamicton. The underlying laminated silt and diamicton units at Samset could then be correlated to the Sanna beds. The lowest diamicton unit at Samset should then be correlated to the Rosenlund diamicton. The uppermost unit of laminated fine sand at Samset could perhaps correspond to the Ekhagen clay. The uppermost unit of laminated sand at Samset can laterally be traced to the sand units at Axamo.

The delta at Axamo displays a paleocurrent towards a northwestern sector, which is likely if the col westwards to the Nissan valley at Olsbo was open. The elevated glacial lake indicates a glacier tongue in the Vättern basin. It is likely that the delta at Axamo was deposited as a marginal delta, at the maximum extension of the glacier that deposited the Öxnehaga diamicton. The uppermost unit of rhythmically laminated silt and clay is correlated with the Ekhagen clay. The complex systems of water eroded trenches northwest of the site is time-correlated with the Ryhov sand.

12:2 The stratigraphy at Mjälaryd and the Tenhults dalen valley

The sediments at Mjälaryd show few similarities with the stratigraphy in the lower Vättern basin and correlations are very uncertain. It is possible, that all the deposits at Mjälaryd are older than the deposits, found in the lower Vättern basin. The southernmost find of the Rosenlund diamicton is in the southernmost parts of Huskvarna (Fig. 150). Here the Rosenlund diamicton is superimposed by a thick sequence of rhythmically laminated silt and clay. The top of the Rosenlund diamicton reaches about +100. About 300 m towards the east, and at about +140 m, there is a small site with

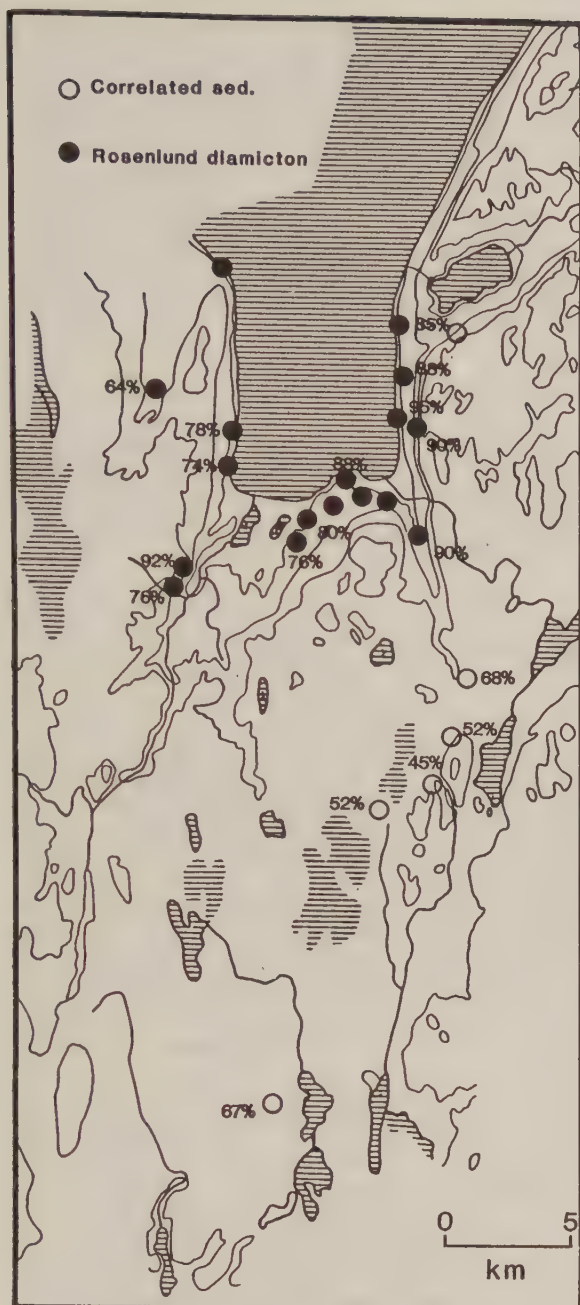


Fig. 150. Sites with the Rosenlund diamicton and sites with sediments corresponding to the Rosenlund diamicton. The % of Visingsö Group of Rocks are shown.

rhythmically laminated silt and clay superimposing about 4 m of trough-bedded cross-laminated gravel and sand. This unit of gravel and sand can be correlated on the surface with the glaciofluvial sediments at Bråneryd, (Fig. 105), about 1 km to the south. The fine-grained sediment superimposing the Rosenlund diamicton is most likely the Sanna beds. This suggests that the glaciofluvial sediments at Bråneryd can correspond to the Öxnehaga diamicton. At Bråneryd the glaciofluvial sediments are superimposed by fine sand, silt and clay grading southwards into varved clay. This varved clay is commonly found in the whole valley. The

stratigraphic position indicates that the varved clay can be correlated with the Ek-hagen clay.

At Uppegården (Fig. 105) the varved clay is superimposing a thin diamicton unit, with a rock fragment composition of 68% Visingsö Group of Rocks and 32% crystalline rocks, which is about the same percentage as in the upper diamicton units at Mjälaryd. Under this diamicton unit, there is a thick unit of diamicton with very low content of Visingsö Group of Rocks (around 10%), which is similar to the content of the lower diamicton units at Mjälaryd.

At Hulugården (Fig. 105) the varved clay is underlaid by a diamicton with low content of Visingsö Group of Rocks, and the unit with high Visingsö Group of Rocks content is missing.

About 1 km north of Klevarp (Fig. 105) there are diamicton units, of undefined genesis, with a high content of Visingsö Group of Rocks, under a thin unit of clay.

A diamicton unit, correlatable to the Öxnehaga diamicton, has not been found at low levels, south of Huskvarna. The diamicton units at Klevarp can perhaps be correlated with the Öxnehaga diamicton, but a correlation with the Rosenlund diamicton is just as likely.

The glaciofluvial sediments at Bråneryd display only minor disturbances, suggesting that the sediments were not overridden by a glacier. This suggests that the sediments were not deposited in front of the advancing Öxnehaga glacier but during a stand still or a retreat of the glacier.

The succession of the rock fragment composition at Mjälaryd is low content of Visingsö Group of Rocks in the lower units and intermediate content of Visingsö Group of Rocks in the upper parts. This is the opposite of the succession from the Rosenlund diamicton to the Öxnehaga diamicton in the lower parts of the Vättern basin. The very low frequency Visingsö Group of Rocks in the lower diamicton units, makes a correlation with the Rosenlund diamicton unlikely. It suggests instead, a correlation between the Rosenlund diamicton and the upper diamicton units at Mjälaryd. If this correlation is correct the lower units at Mjälaryd predates the Rosenlund diamicton. The diamicton samples from Hundhult and Västraby, 3 resp. 4 km south of Mjälaryd, have a similar rock fragment composition as do the upper units at Mjälaryd. This indicates that the glacier, depositing the diamicton, reached further south than Mjälaryd. At Tvätteviken, about 2 km to the south east of Mjälaryd, the rock fragment composition in the diamicton is about 8% Visingsö Group of Rocks indicating that the glacier depositing the upper diamicton units at Mjälaryd was not able to pass over the hills southeast of Mjälaryd.

The most likely correlation of the upper diamicton unit at Mjälaryd is with the Rosenlund diamicton.

The Sanna beds is correlated with the fine-grained sediments below the glaciofluvial sediments at Bråneryd. The glaciofluvial sediments at Bråneryd are correlated with the Öxnehaga diamicton. The rhythmically laminated sediments in the valley are correlated with the Ek-hagen clay. The fluvial erosion in the valley, and the deposits of sand and gravel in the central parts of Huskvarna can be correlated with the Ryhov sand.

12:3 The stratigraphy in the Landsjö dalen valley

Direct correlations between the deposits in the lower Vättern basin and the deposits in the Landsjö dalen valley have not been possible to make.

The striae in the valley show two different systems one from a northern and the other from a western sector (Fig. 138). Striae from the western sector are not found east of about Skärstad and only below +230 m in the western, and +210 m in the eastern parts of the valley.

In the eastern parts of Skärstad, at about +160 m a diamicton is found under about 1 m of massive clay. The diamicton has a rock fragment composition of about 90% Visingsö Group of Rocks and 10% crystalline, which is similar to the rock fragment composition of the upper units at Kaxholmen but not to the lower units. The rock fragment composition at Skärstad suggests a glacier transport along the valley and not from the north. A diamicton transported from the north, from the hills of crystalline rocks less than 300 m away (Fig. 4), should have another rock fragment composition than that at Skärstad.

It is likely that the extension of the glacier from a western sector was about the same as the extension of striae from this sector indicating the diamicton at Skärstad and the upper diamicton at Kaxholmen were deposited by this glacier advance.

The succession of the rock fragment composition at Kaxholmen runs from intermediate amount (about 65%) Visingsö Group of Rocks in the lower units to a high amount (about 80%) Visingsö Group of Rocks in the upper units. This succession only favors a correlation of the upper unit at Kaxholmen with the Rosenlund diamicton. The Rosenlund glacier oscillation was bigger, however, and the glacier was moving towards southeast, over crystalline rocks for some distance before deposition. In this area a glacier coming from the north would have a lower content of Visingsö Group of Rocks, than a glacier coming from a western sector, which had moved over areas with Visingsö Group of Rocks.

This suggests a correlation of the upper diamicton at Kaxholmen with the Öxnehaga diamicton.

In the Tenhultsdalen valley and the Tabergsån valley, there are indications that the extension of the Öxnehaga glacier advance was much smaller than the Rosenlund glacier advance. The Rosenlund glacier would have a larger extension in the Landsjö dalen valley if the front reached at least to Hundhult in the Tenhult valley, about 25 km south of the Landsjö dalen valley.

If the striae from the western sector in the Landsjö dalen were eroded by the Öxnehaga glacier the stratigraphy in the valley would be easier to explain. The lowest diamicton unit at Kaxholmen would then be correlated to the Rosenlund diamicton. The overlying water sorted sediments would belong to the Sanna beds and the upper diamicton at Kaxholmen would be correlated with the Öxnehaga diamicton.

The glaciofluvial sediments hanging on the valley side show a paleocurrent towards the east (Fig. 143) indicating deposition laterally to the Öxnehaga glacier. The lateral delta at Höganäs is the easternmost glaciofluvial deposit in the valley and it is



Fig. 151. The extension of the Öxnehaga glacier in the Landsjö dalen valley.

probably a marginal delta deposited at the maximum extension of the Öxnehaga glacier advance in the valley (Fig. 151).

Most of the glaciofluvial sediments in the valley can be correlated to the Öxnehaga diamicton.

The rhythmically laminated silt and clay below the delta sequence at Höganäs, and east of Drättinge, is possibly correlated with the Sanna beds. The rhythmically laminated sediments superimposing the glaciofluvial deposits are correlated with the Ekshagen clay.

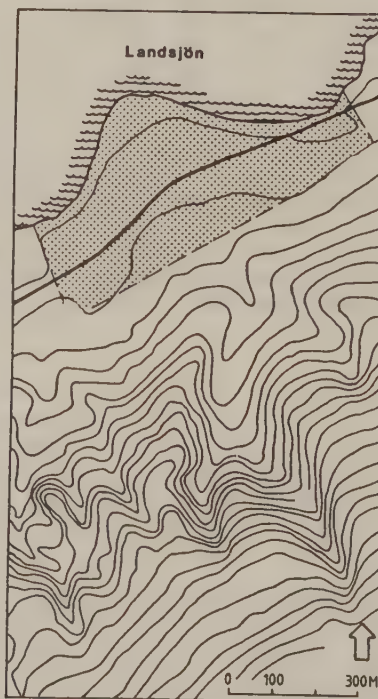


Fig. 152. Ravines and a delta in the Landsjö dalen valley.

The eroded trenches in the valley slopes, especially between Kaxholmen and Drättinge, and the deltas along the south and east shores of lake Landsjön (Fig. 152) are correlated to the Ryhov sand.

12:4 Conclusions

The most likely correlations of the stratigraphy in the lower Vättern basin (Fig. 16) with the surrounding subareas is presented below.

12:4:1 The Kaptensbo beds

The Kaptensbo beds are probably only correlated with the laminated silt and clay below the gravel at Dammhagen. It is possible that the lower gravel unit at Mjälaryd could also be correlated to the Kaptensbo beds.

12:4:2 The Rosenlund diamicton

The Rosenlund diamicton corresponds to the lower gravel units at Dammhagen and to the upper gravel and overlying diamicton unit. The lowest diamicton unit at Samset is perhaps also correlated to the Rosenlund diamicton (Fig. 150).

The gravel deposits at Dammhagen are correlated to the kame deposits at Fågrida and Eckersholm, which then shall be time-correlated to the Rosenlund diamicton. The kame deposits at Fågrida and Eckern are believed to be the outer limit of the glacier oscillations in the Vättern basin (Waldemarson 1981).

12:4:3 The Sanna beds

The Sanna beds can be distinguished neither at Dammhagen nor at Mjälaryd. The fine-grained deposits below the glaciofluvial sediments at Bråneryd in the Tenhult valley are correlated to the Sanna beds. The extensive areas north of the waterdivide, south of the Vättern basin, covered with sand and more fine-grained sediments (Svantesson 1985) should perhaps partly be correlated to the Sanna beds (Fig. 153).

If, as believed, the Öxnehaga glacier did not pass south of the ridge at Eket (Fig. 105) in the Tenhult valley then the lower parts of the varved clay at Uppegården is correlated with the Sanna beds.

In Landsjödalen the rhythmically laminated sediments found below the delta at Höganäs, and 500 m east of Drättinge, are correlated with the Sanna beds.

12:4:4 The Öxnehaga diamicton

The Öxnehaga diamicton can not be distinguished at Dammhagen.

In the Tenhults dalen valley the glaciofluvial sediments at Bråneryd correspond to the Öxnehaga diamicton (Fig. 154). In the Landsjödalen valley, the foreset and the topset beds of the deltaic deposits on the valley slopes, are correlated with the Öxnehaga diamicton. The upper diamicton units at Kaxholmen, Säby and Skärstad are also believed to be part of the Öxnehaga

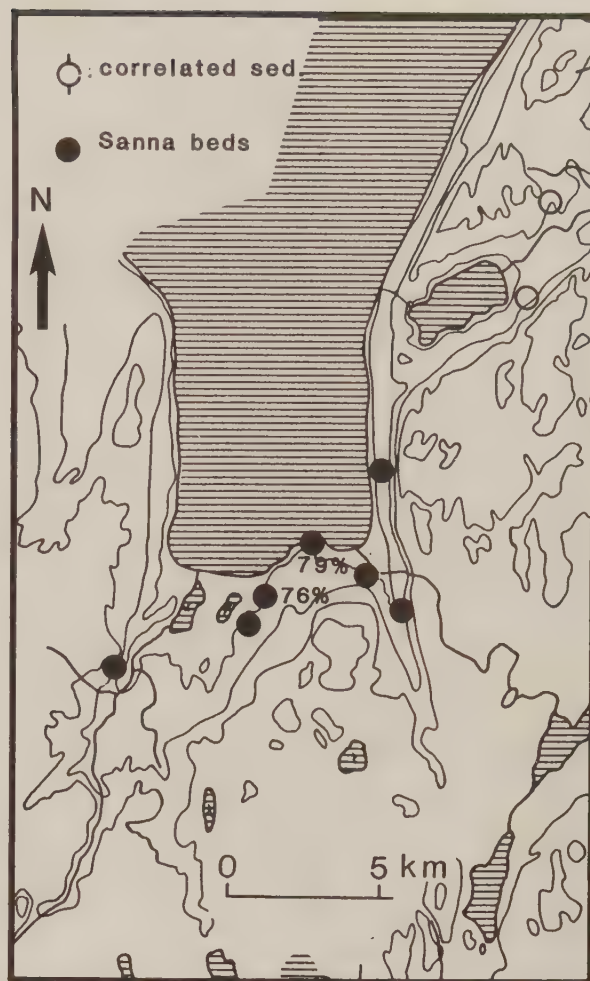


Fig. 153. Sites with the Sanna beds and sites correlated to the Sanna beds. The Visingsö Group of Rocks is shown.

diamicton. The striae pointing towards an eastern sector were cut by the Öxnehaga glacier.

The striae, with a westerly trend in the western slopes of the Vättern basin, are also believed to have been eroded by the Öxnehaga glacier. This indicates that the diamicton unit at Dalvik can be correlated to the Öxnehaga diamicton and the foreset and topset beds in the delta at Axamo correspond to the Öxnehaga glacier advance.

12:4:5 The Ekhagen clay

The Ekhagen clay might correspond to the upper fine grained units and to the diamicton units at Dammhagen and to parts of the glacial lake deposit between the waterdivide and the Vättern basin.

In the Tenhultsdalen valley the Ekhagen clay corresponds to the upper part of the varved clay at Uppegården.

In the Landsjödalen valley the rhythmically laminated clay, superimposing the delta east of Drättinge, is correlated to the Ekhagen clay (Fig. 155).

On the western side of the Vättern basin, the Ekhagen clay corresponds to the fine-grained sediments superimposing the delta at Axamo.

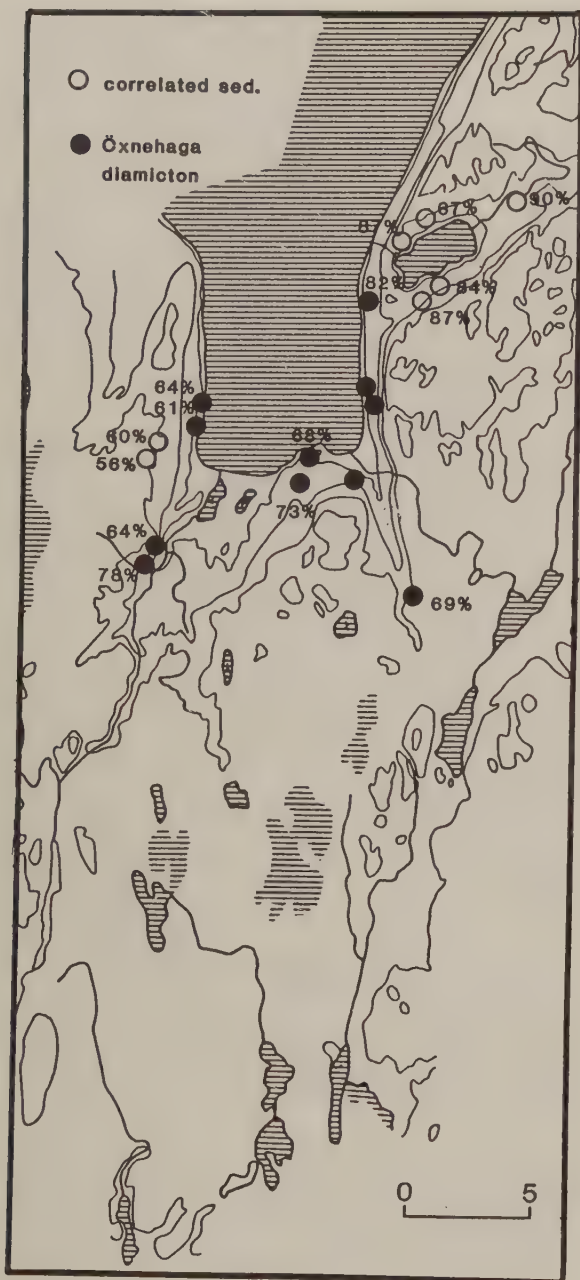


Fig. 154. Sites with the Öxnehaga diamicton and corresponding sediment. The Visingsö Group of Rocks is shown.

12:4:6 The Ryhov sand

The Ryhov sand can only be correlated to erosional features outside the lower Vättern

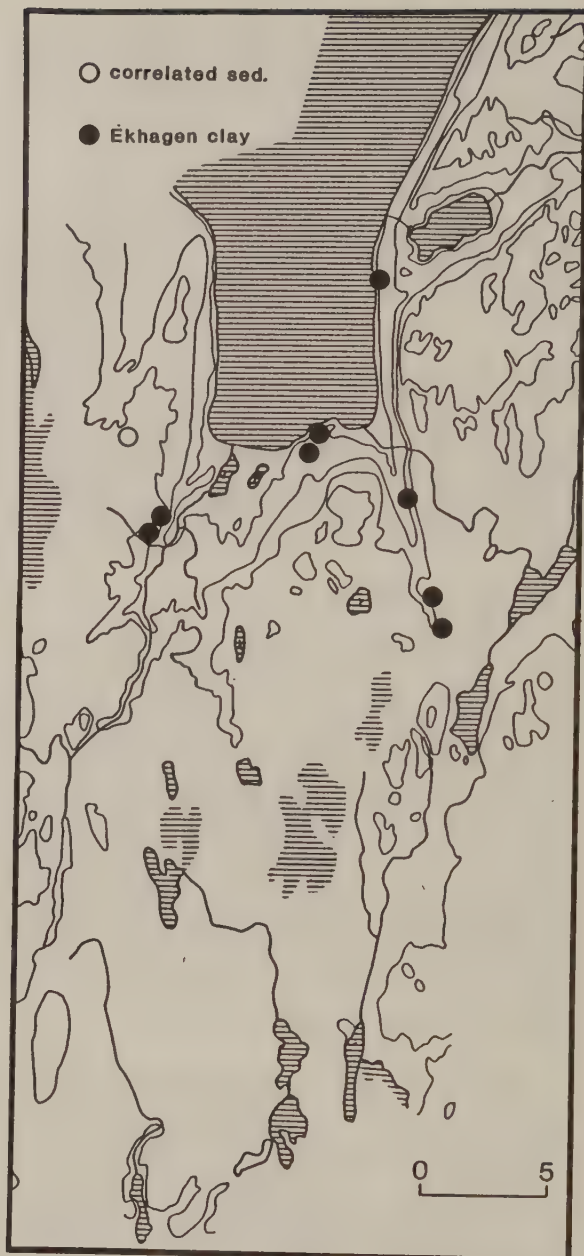


Fig. 155. Sites with the Ekshagen clay and corresponding sediment.

basin, except in the Landsjödalen valley, where the Ryhov sand is correlated with the small deltas on the southern shore of lake Landsjön (Fig. 152).

13 Paleoenvironmental interpretations

The depositional environment of the different stratigraphic units in the lower Vättern basin and correlated units in the surrounding uplands are reviewed below.

13:1 The Kaptensbo beds

In the lower part of the Vättern basin the Kaptensbo beds were deposited in a glacial lake. The intraclasts of diamicton and the dropstones, indicate that parts of the sediments were dropped from ice-bergs or from the sole of a floating glacier.

A major part of the sediments in the Kaptensbo beds was deposited by sediment gravity flow processes. Debris flow and density modified grain flow were the most common flow processes, but sediments deposited by turbidity currents are also found in the Kaptensbo beds. Waterescape structures, formed by fluidized flow, are also common in this stratigraphic unit.

The Kaptensbo beds have, on the western side of lake Vättern, been displaced by glaciotectionic pressure coming from an eastern sector, and at Damnhagen from a northern sector.

The surface of the Kaptensbo beds is often eroded and at some places incorporated in the overlying unit.

13:2 The Rosenlund diamicton

The Rosenlund diamicton in the lower Vättern basin is at least partly deposited under an active glacier and these parts should be called a till. The evidence for this is the tectonic deformation and the incorporation of sediments from the underlying unit. The Rosenlund diamicton consists mostly of reworked glaciolacustrine sediments. The uniform appearance of the diamicton in the whole region, the high degree of consolidation and the jointing of the unit, are properties connected to till deposition.

In the upper parts of the Rosenlund diamicton there are evidences of sediments having been deposited by sediment gravity flows in a subaqueous environment.

Outside the lower part of Vättern basin the described properties of the Rosenlund diamicton are not found.

In the Tenhult valley the Rosenlund diamicton corresponds to the upper diamicton units at Mjälaryd. The lower unit at Mjälaryd is believed to be a till. Overlying units are deposited by sediment gravity flows in both subaerial and subaquatic environment.

In the Tabergsån valley, the Rosenlund diamicton possibly corresponds to glaciofluvial sediments deposited in a subglacial or subaquatic position.

13:3 The Sanna beds

In the lower part of the Vättern basin the Sanna beds consist of glaciofluvial and glaciolacustrine sediments, deposited in deep water.

The Sanna beds consist mainly of glaciofluvial sand, deposited either on the bottom of an about 100 m deep glacial lake

or subglacially deposited. Units deposited by sediment gravity flow processes and by falling out of suspension are also found in the Sanna beds. The Sanna beds show paleocurrents towards a southern sector.

In areas outside the lower part of the Vättern basin the Sanna beds correspond either to rhythmically laminated silt and clay (under +200 m) or to fluvial sands (above +200 m).

13:4 The Öxnehaga diamicton

In the lower part of the Vättern basin most units in the Öxnehaga diamicton are deposited by sediment gravity flow processes in a subaquatic environment, but at some sites, there is evidence of shearing caused by an overriding glacier. It is likely that a floating glacier in the lake Vättern occasionally grounded and deformed underlying sediments and perhaps also deposited some till.

In the Tenhultsdalen valley the Öxnehaga diamicton corresponds to the glaciofluvial sediments at Bråneryd. These sediments show paleocurrents towards the south.

In the Landsjödal valley, the striae eroded from a western sector are correlated with the advance of the Öxnehaga glacier. This indicates that the glacier grounded in the valley and probably deposited till. The under- and overlying rhythmically laminated silt and clay indicate a subaquatic environment before and after the advance of the Öxnehaga glacier. The deltaic sequences hanging on the valley sides, indicate ice contact deposition in a glacial lake with a water level of about +225 m.

On the western slopes of the Vättern basin the striae from an eastern sector were eroded by the Öxnehaga glacier and the associated diamicton at Dalvik is probably a till. The delta at Axamo was built up to a lake level of about +225 m and was deposited during the maximum extension of the Öxnehaga glacier.

13:5 The Ekham clay

In the lower part of the Vättern basin the Ekham clay is deposited in a glaciolacustrine environment. Most parts of the sediment were deposited by falling out of suspension, but at some sites sediment gravity flow deposits were found in the Ekham clay.

Outside the lower part of the Vättern basin, the Ekham clay corresponds to rhythmically laminated silt and clay, deposited in a glaciolacustrine environment.

13:6 The Ryhov sand

In the lower part of the Vättern basin, the Ryhov sand is found as the topset and foreset beds of deltas. The paleocurrents of the deltas were directed towards a northern sector. The sediment was deposited into a low energy water with a level of + 100 m at Jönköping and +105 m at Bankeryd. The Ryhov sand often shows deformation structures, indicating ice contact deposition in a glacial lake.

Outside the lower part of the Vättern basin the Ryhov sand only corresponds to erosional features.

14 The rock fragment composition of different stratigraphic units

The rock fragment composition of more than 300 samples was analyzed from the area. Particles from the Visingsö Group of Rocks, Paleozoic lime stones and crystalline rocks were separated.

The purpose of this investigation was: 1) to find out if different stratigraphic units have different rock fragment composition, 2) to investigate the decline of a component in the direction of ice-movement.

The rock fragment composition of the stratigraphic units are presented in Figs. 150, 153, 154, and 156.

14:1 The Kaptensbo beds

The diamicton units within the Kaptensbo beds contain about 70% Visingsö Group of Rocks and 30% crystalline rocks. All the analyzed samples come from Vilhelmsro or Kaptensbo.

14:2 The Rosenlund diamicton

The rock fragment composition in the Rosenlund diamicton varies between 80-95% Visingsö Group of Rocks and 5-20% crystalline rocks.

On the western side of Lake Vättern the values of Visingsö Group of Rocks are lower than on the eastern side. There is usually a higher percentage of sandstone from the Visingsö Group of Rocks on the western side of the lake than on the eastern side. This is a direct reflection of the extension of the sandstone and shale in the Visingsö Group of Rocks (Fig. 4).

In the Tenhultsdalen valley the Rosenlund diamicton is correlated with the upper diamicton units at Mjälaryd and at Uppegården. The rock fragment composition varies between 42-68% Visingsö Group of Rocks and 58-32% crystalline rocks, with a mean of about 55% Visingsö Group of Rocks and 45% crystalline rocks.

In the Tabergsån valley the Rosenlund diamicton corresponds to the lower gravel units at Dammhagen, which have a rock fragment composition of 45% Visingsö group of Rocks and 55% crystalline rocks. The gravel deposits at Dammhagen are correlated with the ice-contact deposits at Fägrida and Skogslund, about 1 km west of lake Eckern, which have a rock fragment composition similar to the gravel in Dammhagen (Fig. 150).

In the Landsjöådal valley the Rosenlund diamicton is correlated with the lower diamicton units at Kaxholmen, which have a rock fragment composition of about 60% Visingsö Group of Rocks and 40% crystalline rock. Up to 8% Paleozoic limestone are found in a sample from this unit in the Landsjöådal valley.

The Rosenlund diamicton is interpreted as being deposited during a glacier oscillation in the Vättern basin. The extension of this oscillation is based on morphological evidence (Waldemarson 1981). It is supposed to have reached south of the main waterdivide and perhaps further to the south (Fig. 157).

At Lövsåsen (Fig. 150), about 17 km south of



Fig. 156. Sites with the Ryhov sand and correlated sediment. The % Visingsö Group of Rocks is shown.

Barnarp and about 20 km south of the nearest outcrop of Visingsö Group of rocks, the surficial diamicton under the zone of leaching, has a content of 67% Visingsö Group of Rocks and 33% crystalline rocks. Under this unit there is a diamicton with about 29% Visingsö Group of Rocks and 71% crystalline rocks. The upper diamicton unit is possibly correlatable with the Rosenlund diamicton.

At Västraby (Fig. 105), about 4 km south of Mjälaryd a surficial diamicton sample shows a rock fragment composition of about 56%

Visingsö Group of Rocks and 44% crystalline rocks. At Hundhult about 3 km south of Mjälaryd, a diamicton unit correlated to the Rosenlund diamicton has a rock fragment composition of about 46% Visingsö Group of Rocks and 54% crystalline rocks.

South of Uvaberget, at Tvätteviken, about 2 km southwest of Mjälaryd, the rock fragment composition in surficial diamicton samples have about 8% Visingsö Group of Rocks and 92% of crystalline rocks. This suggests a correlation to the lower diamicton units at Mjälaryd, which are supposedly older than the Rosenlund diamicton. This indicates that the glacier, depositing the Rosenlund diamicton did not pass over the hills southwest of Mjälaryd, and limits the extension of the Rosenlund diamicton as well (Fig. 157). The rock fragment composition of the Rosenlund diamicton shows a general decrease of the Visingsö Group of Rocks towards the south (Fig. 150).

14:3 The Sanna beds

The rock fragment composition of units from the Sanna beds has only been recorded from the Rosenlunds bankar, where there is about 79% Visingsö Group of Rocks and 21% crystalline rocks. Otherwise this unit is usually too fine grained to contain enough clasts for rock fragment analyses.

14:4 The Öxnehaga diamicton

The Öxnehaga diamicton has a heterogeneous rock fragment composition. Even closely spaced samples can differ as much as 20% in the content of Visingsö Group of Rocks. The mean content of Visingsö Group of Rocks is about 70%. Sites with the Öxnehaga diamicton are shown in Fig. 154.

The Öxnehaga diamicton is correlated to the diamicton unit at Dalvik on the western slopes of the Vättern basin. The rock fragment composition in the diamicton at Dalvik is about 60% Visingsö Group of Rocks.

In the Landsjödalen valley the upper diamicton units at Kaxholmen and Skärstad are correlated to the Öxnehaga diamicton. These units have a higher content Visingsö Group of Rocks than the Öxnehaga diamicton in the lower part of the Vättern basin, which probably is due to local outcrops of Visingsö Group of Rocks in the lower parts of the Landsjödalen valley (Svantesson 1985).

14:5 The Ekshagen clay

The low content of gravel size clasts in the Ekshagen clay has not admitted rock fragment analyses.

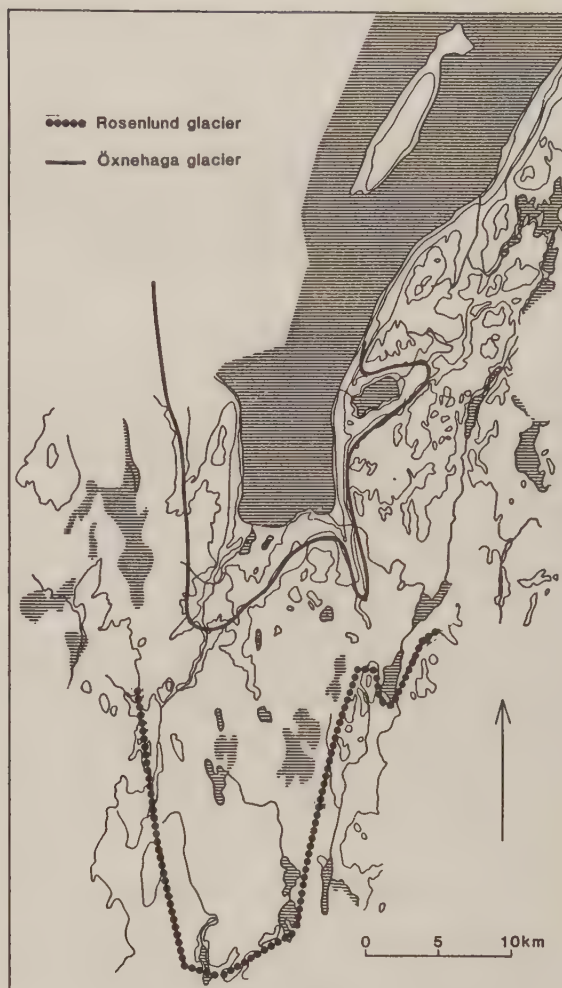


Fig. 157. The maximum extent of the Rosenlund- and the Öxnehaga glacier.

14:6 The Ryhov sand

Only one rock fragment analysis was made in the Ryhov sand. The sample comes from Jägmästaren in the central parts of Jönköping. The analysis shows a content of about 44% Visingsö Group of Rocks (Fig. 156). This is a very low frequency for a sediment deposited on Visingsö Group of Rocks (Fig. 4), but it corresponds to the rock fragment composition at Damnhagen. This confirms that the Ryhov sand is derived from earlier deposited sediments south of Jönköping.

15 The deglaciation history of the investigation area

The stratigraphy in the Vättern basin shows a complex deglaciation history of the investigation area. After the first retreat of the ice, two readvances are recorded. Each retreat was followed by a glacial lake stage. These different events are described and summarized in this chapter.

15:1 The first glacial lake

There are very few traces of the first glacier retreat from the area, except kame morphology in the southern part of the investigation area, which is supposed to emanate from this retreat.

When the glacier front was situated north of the main waterdivide a glacial lake was formed between the active ice front and the higher areas to the south. How far to the north the active margin retreated is not clear.

The ice-dammed lake in the Vättern basin contained numerous ice-bergs dropping material into the fine sediments at the bottom of this glacial lake.

During this retreat and the following readvance the Kaptensbo beds and perhaps also the laminated silt and clay at Dammhagen (Chapter 12:1) are supposed to have been deposited.

15:2 The Rosenlund glacier readvance

The retreat of the glacier was followed by a readvance in the Vättern basin. During the readvance the glacier incorporated and homogenized previously deposited glaciolacustrine sediments, which can be seen at Vilhelmsro (Chapter 7:2).

The advance of the Rosenlund glacier reached as far as south of the waterdivide and probably as far as to the vicinity of Vaggeryd (Fig. 2). The map of the probable maximum extension of the Rosenlund glacier (Fig. 157) is based on the ice contact morphology south of the waterdivide described by Waldemarson (1981), the rock fragment composition of different stratigraphic units and the stratigraphy at Dammhagen (Chapter 12:1).

During the retreat of the Rosenlund glacier a zone of stagnant ice was left in front of the active ice margin. In this zone glaciofluvial sediments with ice-contact morphology and structures were deposited, like the deposits at Eckersholm, Fägrida and Byarum. Outside the zone of stagnant ice earlier deposited sediments were buried by sandur sediments. Whether the kettle holes south of Vaggeryd emanate from ice bodies left by the Rosenlund glacier or from the first deglaciation is not clear.

15:3 The second glacial lake

When the Rosenlund glacier retreated north of the waterdivide, a new glacial lake was formed between the glacier margin and the upland in the south. During this deglaciation and in the glacial lake the gravel units at Dammhagen, which corresponds to the Rosenlund diamicton, were deposited.

Close to the active glacier margin and under

the floating glacier front diamicton units were formed. Further away from the ice front glaciolacustrine sediments and dropped sediments were deposited. The high rate of sedimentation of fines diluted the diamicton deposited by rain out from floating ice-bergs and the result is the silty sediment with dropstones found between Jönköping and the waterdivide (Svantesson 1985).

Parts of the Sanna beds were perhaps formed during this deglaciation.

How far north the glacier retreated during this stage is not clear, but it is possible that the thresholds eastwards over the Östergötland plain to the Baltic Ice Lake or even the thresholds north of mount Billingen (Fig. 1), were open (Björck and Digerfeldt 1984).

According to Waldemarson (in prep) there is a unit of rhythmically laminated silt and clay with about 300 laminae of fine clay between a unit correlated to the Rosenlund diamicton and a unit correlated to the Öxnehaga diamicton. This suggests there are about 300 years from the time the Rosenlund glacier left the area until the Öxnehaga glacier overrode the area.

15:4 Öxnehaga glacier readvance

Once again the glacier advanced in the Vättern basin in a high elevated ice-dammed lake. It is likely that parts of the Sanna beds, at Rosenlunds bankar and Sanda were deposited during this advance. The Öxnehaga diamicton was deposited during the maximum extent of this oscillation and during the deglaciation.

How far to the south the glacier oscillation reached has not been possible to find out exactly, but it is unlikely that the oscillation reached as far as Mjälaryd in the Tenhultsdalen valley. The maximum extent can be found somewhere between Bråneryd and Mjälaryd (Fig. 105). Between these two sites there are two ridges, at Tenhult and at Eket (Fig. 105). From the rock fragment composition record, from the valley and from the stratigraphy the oscillation did probably not pass Hulugården (Fig. 105). This suggests the ridge at Eket was formed during the maximum extent of the Öxnehaga glacier oscillation.

In the Tabergsån valley there are very few traces of this glacier advance. The southernmost track of this advance is the site 500 m south of Tokarp, but the advance possibly reached further to the south.

In the Landsjödalen valley the striae from a western sector are supposed having been formed during this oscillation. The oscillation probably passed Skärstad but probably not far northeast of Berghem, 500 m further to the northeast (Fig. 151).

In the western slopes of the Vättern basin the striae from an eastern sector were probably formed during the Öxnehaga glacier advance. The delta at Axamo probably marks the maximum extension of the Öxnehaga glacier advance.

According to J.O.Norrman (pers com) the ice-contact glaciofluvial deposits, "Lindhultsplatån" and "Dyngkärsmo", northwest of the investigation area, were

also deposited at the maximum extension of the Öxnehaga glacier advance (Fig. 157). The marginal glaciofluvial deposits connected with the Öxnehaga glacier on the western side of the Vättern basin, Axamo, the Lindhultplatån and Dyngkärrsmo, display a paleocurrent towards a western sector. These marginal deposits are situated about 10 km apart. All the deposits are lying on the same meridian and are formed up to +225 m. This suggests that the glacier had a front, with an almost north-south margin on the western side of the Vättern basin.

The marginal glaciofluvial deposits in the Landsjödalen valley, connected with the Öxnehaga glacier, display a paleocurrent towards an eastern sector. The striae, connected with the Öxnehaga glacier on the western side of the Vättern basin, are pointing towards a western sector and on the eastern side towards an eastern sector.

The glaciotectionic structures at Vilhelmsro and Kaptensbo on the western shore of lake Vättern, indicate a glaciotectionic stress from an eastern sector.

At Rosenlund and Sanda there is evidence of glacial shear stress directed towards the south and connected with the Öxnehaga glacier.

These different directions in such a small area, emanating from the same glacier advance are difficult to explain. The most likely explanation is that a glacier tongue advanced in the Vättern basin, perhaps as a surge (c.f. Wright 1973, 1980). When the front reached the high southern end of the basin the glacier met a much higher frictional resistance from the slope and from the bedrocks in the slope than the friction from the soft clay and silt in the basin (c.f.

Boulton and Jones 1979). This damming forced the glacier front to rise. During the rise of the front, the glacier spread from the area where it rose and the directions of glacier movement was formed as described above. A local dome, with a short duration, was formed in the southern end of the Vättern basin during this stage (Fig. 157). It is possible that the glacier tongue increased the precipitation over the glacier's southernmost parts, at which a local dome was formed.

15:5 The third glacial lake

When the Öxnehaga glacier retreated, an ice-dammed lake was formed between the glacier and the waterdivide (Fig. 3). On top of the Öxnehaga diamicton the Ekshagen clay was deposited in a glacier lake with a water level of about +220 m. It is possible that a marginal glacial lake existed, in the southernmost parts, during the Öxnehaga glacier readvance.

In the period during which the Vättern basin was in contact with the Baltic Ice Lake the Ryhov sand was deposited. The sand was derived from erosion of the surrounding slopes. The ice-contact structures in the deltas at Ryhov, 500 m south of Tokarp and at the western center of Jönköping suggest that the glacier tongue stagnated and that ice-bodies were left in the lower parts of the basin.

After the drainage at the northern end of Mt. Billingen the water level in the Jönköping area dropped below the present lake level. Deposits from this level are submerged. Norrman (1964, 1979) has recorded depositional and erosional forms from this stage.

16 Regional implications of the stratigraphy and deglaciation history of the south Vättern basin

Three recent works deal with the Vättern basin. The statements in Bjelm's (1976) brief study of the south Vättern basin are partly verified in this thesis, and also some correlations to his central area around Eksjö are possible to make.

The works by Johansson (1979) and Svantesson (1981) from the Östergötland plain record only minor oscillation around the middle Swedish endmoraine zone.

The striae on the western parts of the Östergötland plain are recorded by Svantesson (1981). He shows the oldest direction from northeast, the younger from north and the youngest from northwest. Svantesson (1981) does not make any certain correlations of the youngest striae to a certain end moraine complex. The sediments are built up to about +140 m. This endmoraine complex is correlated to the younger Dryas readvance (Berglund 1979, Berglund and Mörner 1984).

The works by Björck and Digerfeldt (1984, 1986) show an oscillation of the glacier front around the northern tip of Mt. Billingen. The oscillation is dated by a combination of litho- bio- and chronostratigraphy to the early cool part of the Younger Dryas Chronozone. The threshold of the Vättern glacier lake and the Baltic Ice Lake north of mount Billingen were blocked for about 600 years. Björck and Digerfeldt (1984) state that the glacier readvanced more than 30 km on the western side of Mt. Billingen. Such an extensive readvance on the western side of Mt. Billingen was probably reinforced in the deep Vättern basin filled with silt and clay, which reduces the friction between the glacier sole and the substrate considerably.

In Lagerlund et al (1983) the E-line (12 200 BP) corresponds to maximum extent of the Rosenlund glacier and the F-line (12 000 BP) corresponds to the maximum extent of the Öxnehaga diamicton. The investigations suggests a slightly different configuration of the Öxnehaga glacier margin (Fig. 157). In Lagerlund et al there is about 200 years between the Rosenlund and the Öxnehaga glacier. At A6 in the eastern parts of Jönköping 300 varves are found beneath the Öxnehaga diamicton (Waldemarson in prep.). This indicates a period of about 300 years between the retreat of the Rosenlund glacier and the readvance of the Öxnehaga glacier in the area. This long period might suggest a correlation to the oscillations around the tip of Mt. Billingen, which then indicates that the Öxnehaga glacier readvances during the Younger Dryas Chronozone.

The Öxnehaga glacier reached about +225 m in the investigation area, but only about +140 m in the Östergötland plain (Johansson 1979, Svantesson 1981). A correlation between the Öxnehaga glacier and the Younger Dryas readvance in the Östergötland plain (Skövde line, Berglund 1976, 1979, Berglund and Mörner 1984), indicates that the Öxnehaga glacier had a gradient towards the north in the Vättern basin north of the investigation area. This is theoretically possible if an icedome existed in the southern Vättern basin, but not likely.

To solve these problems more sedimentological and stratigraphical work is needed, especially on the western side of the Vättern basin and at Visingsö (where reconnaissance investigations are made).

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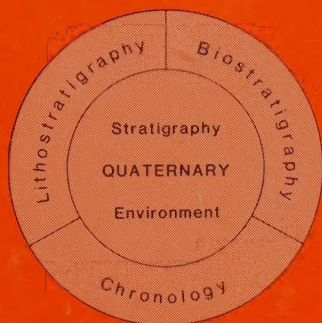
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